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Determining Individual Tree Shade Length: A Guide for Silviculturists

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Research Summary

Shade may be critical through the summer for conifer regeneration survival on warm, dry sites. In the Northern Hemisphere, the sun produces its shortest shadow during the summer because the sun is highest in the sky on June 21, the summer solstice. The sun produces its longest shadow in the Northern Hemisphere on December 21, the winter solstice. During the day, the shortest shadow occurs at solar noon, when the sun reaches its highest angle relative to a point on the ground. Shadow lengths for the same period vary by latitude, aspect, and slope; southerly aspects have shorter shadows than northerly aspects at the same time. Differently shaped trees also produce different shadow lengths.

This guide provides to silviculturists a method for determining tree shadow lengths in a straight line from the tree's base to the shadow tip from southern Utah to northern Idaho for May 10 through October 11 on different slopes, aspects, and for two tree shapes. Tables and graphs provide shade lengths based on a tree length factor that describes shadow length as a function of tree height. Tree length factors for solar noon and 2 hours before and after solar noon are provided for cylinder-shaped trees. Tree length factors for solar noon are provided for cone-shaped trees. Information about shadow angles and shadow sweep rates are also provided.

Silviculturists could combine this information with other data on daily, solar surface, and air temperature to tailor tree marking to prescription requirements.

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In some environments, successful natural conifer regeneration depends on site protection. In many cases, existing overstory offers the best opportunity to protect regeneration from potentially damaging agents such as wind, frost, hail, or solar radiation. Of these, solar radiation often determines seedling survival and growth. Conifers require threshold levels of sunlight for growth, but solar radiation also generates heat within and around the seedling especially at the soil surface (Childs and others 1985; Helgerson 1990). Lethal temperatures may preclude conifer regeneration in large openings on warm, dry sites.

In central Idaho, natural regeneration appears to require site protection in the warm, dry grand fir/white spirea habitat type (Geier-Hayes 1994) and in the dry Douglas-fir habitat types. Here, natural regeneration survival may depend on shade during periods when solar radiation is most intense.

In the Northern Hemisphere, a tree casts its longest shadow about December 21, on the winter solstice, and its shortest shadow about June 21, on the summer solstice. From the summer to the winter solstice, shadows lengthen, while from the winter to the summer solstice, shadows become shorter. During the day, a tree casts its shortest shadow at solar noon when the sun reaches its highest angle relative to a point on Earth. In the Northern Hemisphere, the sun reaches its highest angle at azimuth 180°, producing a shadow that points toward azimuth 0°. Solar noon occurs around the same time each day and deviates only a maximum of one-half hour throughout the year. Appendix A provides a method to determine the local time of solar noon for any location.

Because shadows fall due north at solar noon, aspects at a corresponding angle east or west of north are mirror images and produce the same length shadow. For example, same-sized trees cast the same length shadow at solar noon on aspects facing east (90° east of north) and west (90° west of north). Other corresponding aspects are northeast and northwest (45° east or west of north), and southeast and southwest (135° east or west of north). Trees also cast the same length shadows on corresponding aspects at corresponding sun time. That is, trees cast the same length shadow on an east aspect (90° east of north) 2 hours before (sun time –30°) solar noon as trees on a west aspect (90° west of north) 2 hours after (sun time +30°) solar noon because the sun angle at those two times is the same relative to solar noon (sun time 0°). At any one time, however, shadow lengths on corresponding aspects do not correlate except on north and south aspects. For example, 2 hours before solar noon, the shadow lengths on an east aspect will be shorter than the shadow lengths on a west aspect.

Objective of This Guide

This guide provides silviculturists with a method for determining shade lengths and shade patterns to assist in writing prescriptions for stands where shade may be critical for natural regeneration. It is also intended as a marking guide to fulfill prescription requirements. It is beyond the scope of this paper to recommend when shade may be required.

Methods

The equations for this guide were modified from Satterlund's total shade area calculations (1983). We modified the equations to calculate total shadow length in a line from a tree's base to the top of the shadow.

We started by calculating sun angle and sun azimuth for various dates, times, and latitudes. We chose dates at 2-week intervals from May 10 to October 11, using June 21, the summer solstice, as a reference. These dates bracket the "critical season" of June through August, when seedlings suffer the most damage from solar radiation. We used two solar time periods, 0° (solar noon), and 30° (2 hours before or after solar noon), because the most intense solar radiation occurs around solar noon. We included 11 latitudes from 38° N (southern Utah) to 48° N (northern Idaho).

We used the calculated sun angle and sun azimuth for the chosen dates, times, and latitudes to calculate shadow lengths and directions for two reference trees on flat ground. We arbitrarily defined one tree as a 90-foot cylinder with a 10-foot conical top and the other tree as a 100-foot cone (fig. 1). We chose the cylinder shape to represent species such as ponderosa pine and Douglas-fir and the cone shape to represent species such as grand fir and spruce.

Next we calculated a correction factor for various slope aspects and slope angles at solar noon. To simplify the results, we chose eight aspects: 0° (north), 45° (northeast), 90° (east), 135° (southeast), 180° (south), 225° (southwest), 270° (west), and 315° (northwest). However, we ran calculations for only north, northeast, east, southeast, and south because northwest, west, and southwest are corresponding aspects of northeast, east, and southeast, respectively. We used five slope angles: 0° (flat ground), 9° (15 percent slope), 17° (30 percent slope), 24° (45 percent slope), and 31° (60 percent slope). Using the correction factor, we corrected the flat ground shadow

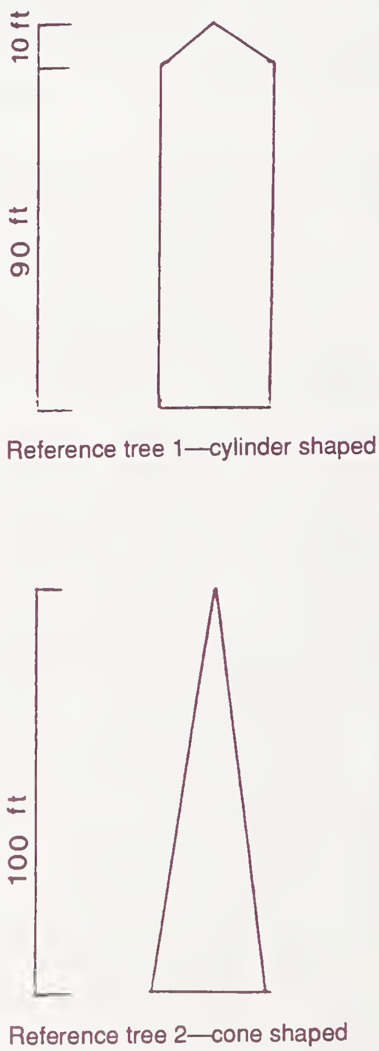


Figure 1—Reference trees for determining shadow lengths.

lengths for various slope and aspect combinations. This correction converted flat ground shadow lengths to slope distance.

We verified shadow length from sun angles calculated for specific dates and times using Hewlett-Packard Mechanical Engineering Design 30, a computer aided design software. We modified some of Satterlund's equations based on output from the computer aided design. Shadow projections from the computer aided design agreed with the modified equations to 0.01 feet. We conducted a small field sample to verify the shadow lengths and shadow azimuths determined by the modified equations. Shadow lengths in the field sample agreed with the calculated shadow lengths within 8 feet for trees of various heights. Shadow azimuths agreed within 1°.

We calculated shadow sweep angle for a 4-hour period for the latitudes and dates to determine shade patterns. Shadow sweep angle is defined by the shadow azimuths 2 hours before and 2 hours after solar noon. Sweep per hour was calculated by dividing shadow sweep angle for the 4-hour period by four. We developed a computer model to derive the tree length factors.

Results

We reduced the shadow length calculations to a "tree length factor" for the dates, aspects, and slopes. The tree length factor describes shadow length as a function of tree height (fig. 2). For example, on June 21 at latitude 44° N at solar noon on flat ground, the cylinder-shaped tree in figure 2 casts a shadow with a tree length factor of 0.48. The shadow is roughly half a tree length (tree length factor x tree height = shadow length). At latitude 44° N, a tree 80 feet tall casts a shadow of about 38 feet on June 21 at solar noon on flat ground (80 feet x 0.48 = 38 feet).

The example calculation in appendix B shows how such figures were derived on the worksheet. The tree length factor provides a useful tree marking guide because one can visualize half a tree length easier than 38 feet in the field. A single tree length factor can apply to different height trees in a target stand. Therefore, one calculation for a target stand (as long as aspect, slope, and tree form remain the same) may suffice.

Appendix C provides tree length factors for cylinder-shaped trees on flat ground, and north and south aspects at solar noon and 2 hours before and after solar noon. Sun angles 2 hours before and 2 hours after solar noon produce the same tree length factor. The sun angle at these two times is the same (sun time 30°) relative to solar noon (sun time 0°). The only difference is the shadow's azimuth.

Appendix C demonstrates how quickly shadow lengths change during the day, particularly at more southerly latitudes. For example, 2 hours before solar noon on June 21 at latitude 38° N, the tree length factor for a cylinder-shaped tree on flat ground is 0.65. At solar noon 2 hours later, the tree length factor reduces to 0.38.

Appendix D shows the shadow sweep angle for a cylinder-shaped tree on flat ground 2 hours before to 2 hours after solar noon, based on the calculated azimuths and shadow lengths. During this 4-hour period, the widest shadow sweep angle occurs on the summer solstice. On this date, tree shadows cover a wider angle but less total area than on any other day because shadow lengths are shortest on this day. The shadow moves fastest on this date; it shades any one point for the shortest time. After the summer solstice, the shadow sweep angle for the 4-hour period decreases while

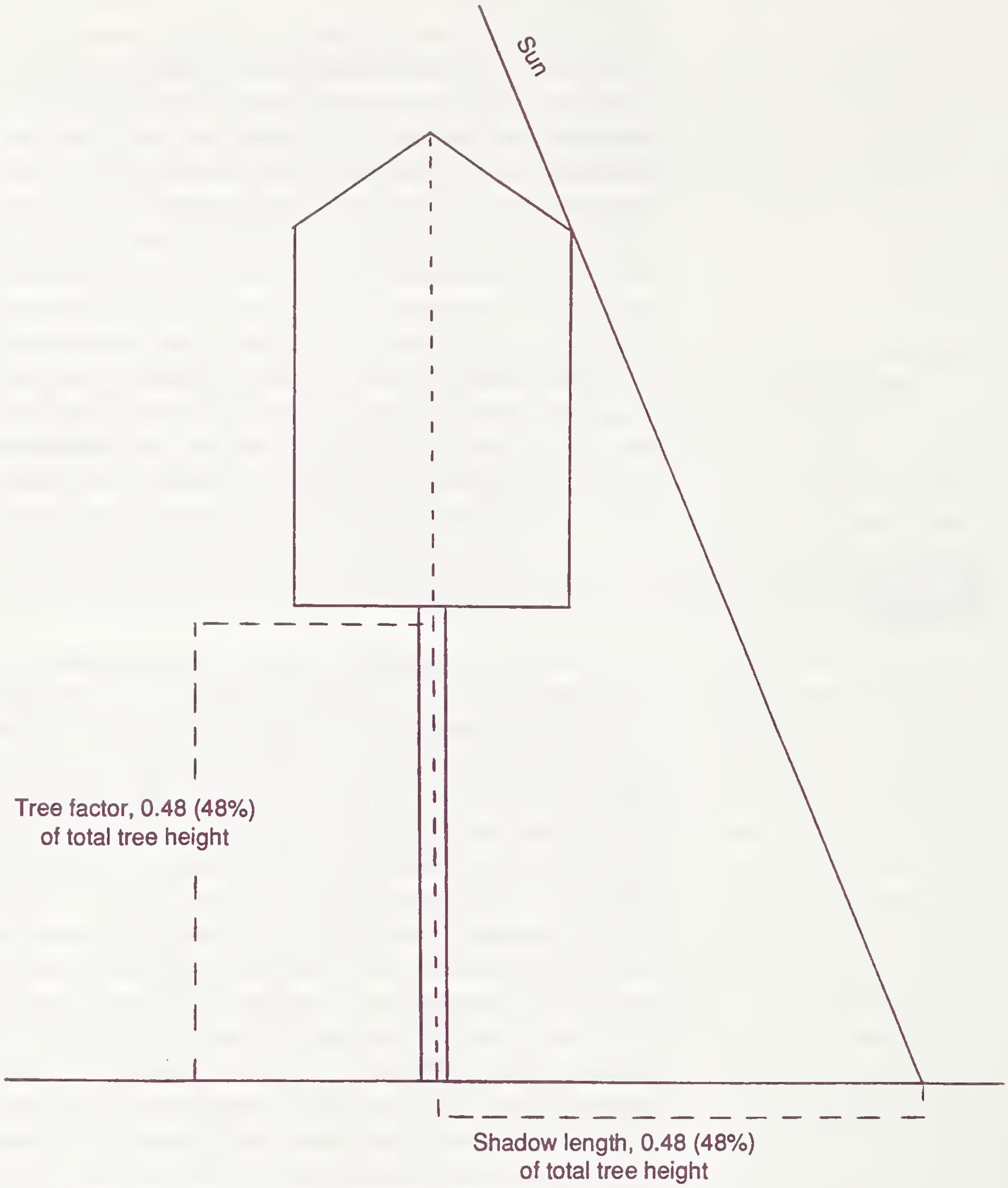
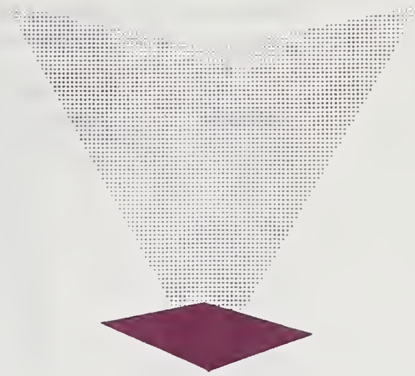


Figure 2—An example of tree length factor and shadow length based on tree length factor.

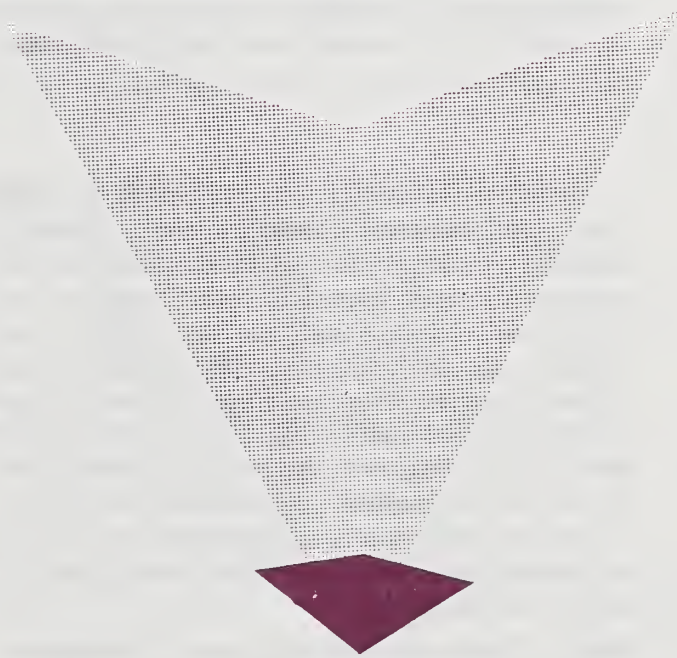
shadow length and duration at any one point increases. The most narrow shadow sweep angle occurs on the winter solstice.

Shadow sweep angle also differs by latitude (fig. 3). From latitudes 38° N and 48° N, the widest shadow sweep angle occurs at latitude 38° N and the narrowest at latitude 48° N. On the summer solstice, the shadow at 38° N moves 34.6° per hour (table 1). At 48° N, the shadow moves 27.4° per hour. Differences in shadow sweep angle decrease between latitudes as Earth moves from the summer to winter solstice. On the winter solstice the shadow moves at virtually the same rate between latitudes; at latitude 38° N the shadow moves at 14.9° per hour and at 14.1° per hour at latitude 48° N.

Tree length factors obtained from appendices E and F deviated an average of –0.008 (–0.8 percent) from tree length factors calculated by the computer model (assumed to be actual shadow lengths) for 45 various-sized



38°N	Solstice	Total angle	Tree length factor Solar noon
	Summer	138.2°	0.38
	Winter	59.6°	1.83



	Summer	109.6°	0.56
48°N	Winter	56.4°	2.98

Figure 3—Shadow sweep for a 4-hour period on the summer (solid black) and winter (stippled) solstice for latitudes 38° N and 48° N.

theoretical trees on different aspects and slopes for June 21 at solar noon. Of the tree length factors, 60 percent were under or exact predictions while 40 percent were longer than tree length factors from the computer model. The largest overprediction for the theoretical data set was 5 feet. Because it is probably impossible to estimate much closer than 5 feet in the field, the variation in tree length factors derived from appendices E and F are probably less than the variation in shadow length estimates by field users.

Table 1—Shadow sweep per hour on the summer and winter solstice for six latitudes.

Latitude	Summer solstice sweep per hour	Winter solstice sweep per hour
	Degrees	
38	34.5	14.9
40	32.9	14.7
42	31.4	14.5
44	30.0	14.4
46	28.7	14.2
48	27.4	14.1

Combining shadow length and shadow sweep angle provides most of the information needed about shade cast by individual trees. During the 4-hour period, a tree casts its longest shadow across the narrowest angle on the winter solstice and its shortest shadow across the widest angle on the summer solstice (appendix D). After the summer solstice and through the critical season for natural regeneration, shadow length increases while the width of the shadow sweep angle decreases.

Using the Guide

Appendices E and F show tree length factors for latitudes 38° N to 48° N (see table 2 to determine appropriate latitude for a location). Appendix E displays tree length factors for cylinder-shaped trees, and appendix F displays tree length factors for cone-shaped trees. Comparing appendices E and F demonstrates that tree form affects tree length factors. Cylinder-shaped trees produce longer shadows than cone-shaped trees. The 100 foot cylinder-shaped reference tree produced a shadow 13 feet longer than the 100 foot cone-shaped reference tree. In the summer, cylinder-shaped trees intercept the sun with the crown edge while cone-shaped trees intercept the sun at the highest point on the tree (fig. 4).

Users of this guide can determine the tree length factor from the following steps (appendix B provides a worksheet for calculations and an example calculation):

Step 1—Determine target stand variables

1. Latitude (see table 2).
2. Azimuth or aspect (see table 3 for grouping corresponding aspects).

Table 2—Reference locations for determining latitude.

Latitude	*Location*
38° N	13 miles north of Panguitch; 9 miles north of Monticello, UT
39° N	3 miles north of Fillmore; at Green River, UT
40° N	14 miles south of Provo; 30 miles south of Vernal, UT
41° N	13 miles south of Salt Lake City; 16 miles south of Ogden, UT
42° N	Border between Utah and Idaho
43° N	At Glenns Ferry; 12 miles north of Pocatello, ID
44° N	5 miles north of Horseshoe Bend; 2 miles north of St. Anthony, ID
45° N	1.5 miles north of New Meadows; 9 miles south of Salmon, ID
46° N	5 miles north of Grangeville, ID
47° N	6 miles north of Bovill; 2 miles south of Clarkia, ID
48° N	20 miles north of Coeur d'Alene, ID

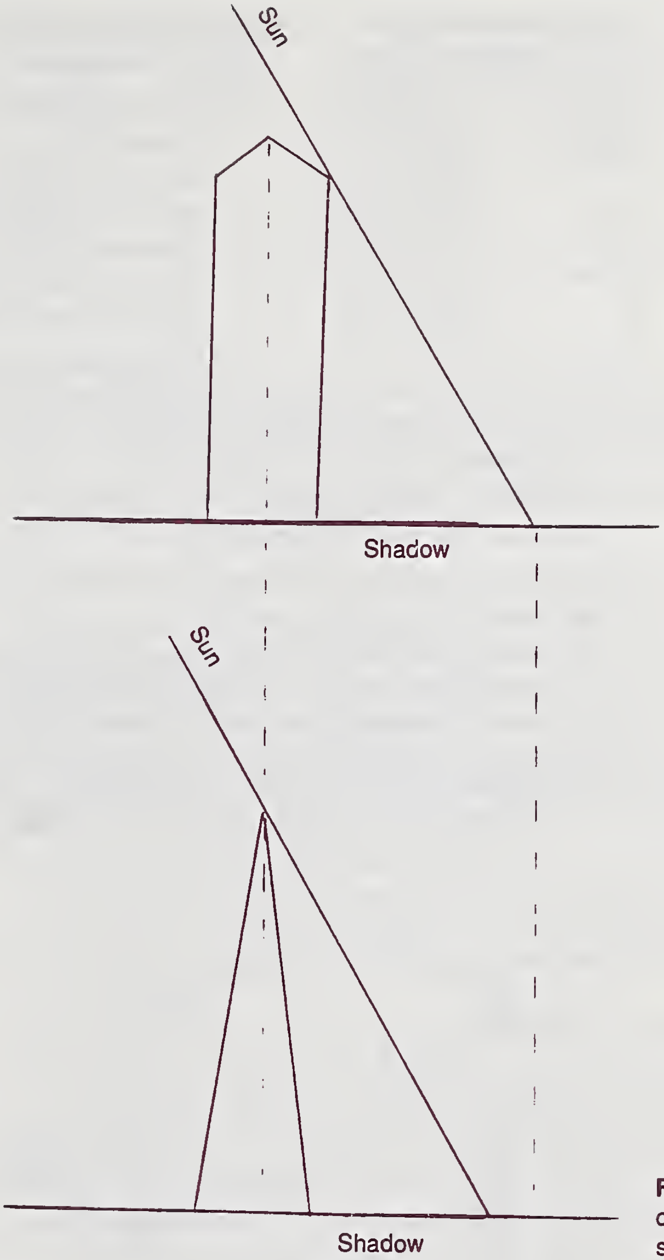


Figure 4—Sun intercept for cylinder-shaped and cone-shaped trees.

3. Percent slope (convert slope degrees to percentage by multiplying the tangent of the slope angle by 100).
4. Target date (such as June 21).

Step 2—Determine average stand variables

To locate the appropriate appendix for the target stand, measure or estimate the following variables for an "average" overstory tree. Determine an "average tree" for each tree form in mixed species stands. See figure 5 for variable definitions of tree height, cone length, and crown radius.

Calculate cone length percentage,

$$\text{cone length percent} = (\text{cone length/total tree height}) \times 100 \qquad (1)$$

Step 3—Determine the appropriate appendix

Determine the appropriate appendix from table 4 using cone length percentage (equation 1) and latitude.

Table 3—Azimuth of corresponding aspects.

Aspect	Azimuth (°)
N	337.5-22.5
NE/NW	22.5-67.5
	292.5-337.5
E/W	67.5-112.5
	247.5-292.5
SE/SW	112.5-157.5
	202.5-247.5
S	157.5-202.5

Step 4—Determine the tree length factor

Using the target stand variables from step 1:

a. Locate appendix selected from step 3 for the appropriate latitude. Read the tree length factor for June 21 directly from the boxed table (instructions b) or use the graphs (instructions c). (Note: the tree length factor for the summer solstice and for the critical season are essentially the same.)

b. Do the following to determine the tree length factor from the boxed table:

b1. Locate the appropriate aspect group (flat ground, N, NE/NW, E/W, SE/SW, or S.

b2. Locate the closest slope (15, 30, 45, or 60 percent).

b3. Read the tree length factor.

c. Do the following to determine the tree length factor from the graphs for dates other than June 21:

c1. In appendix E or F, locate the graph for the closest target stand aspect group (flat ground, N, NE/NW, E/W, SE/SW, or S).

c2. Locate the graph line for the closest slope (15, 30, 45, or 60 percent).

c3. Locate the target date along the horizontal axis.

c4. Read up to the selected line from the target date on the bottom of the graph then across to the scale at the left of the graph to determine the tree length factor.

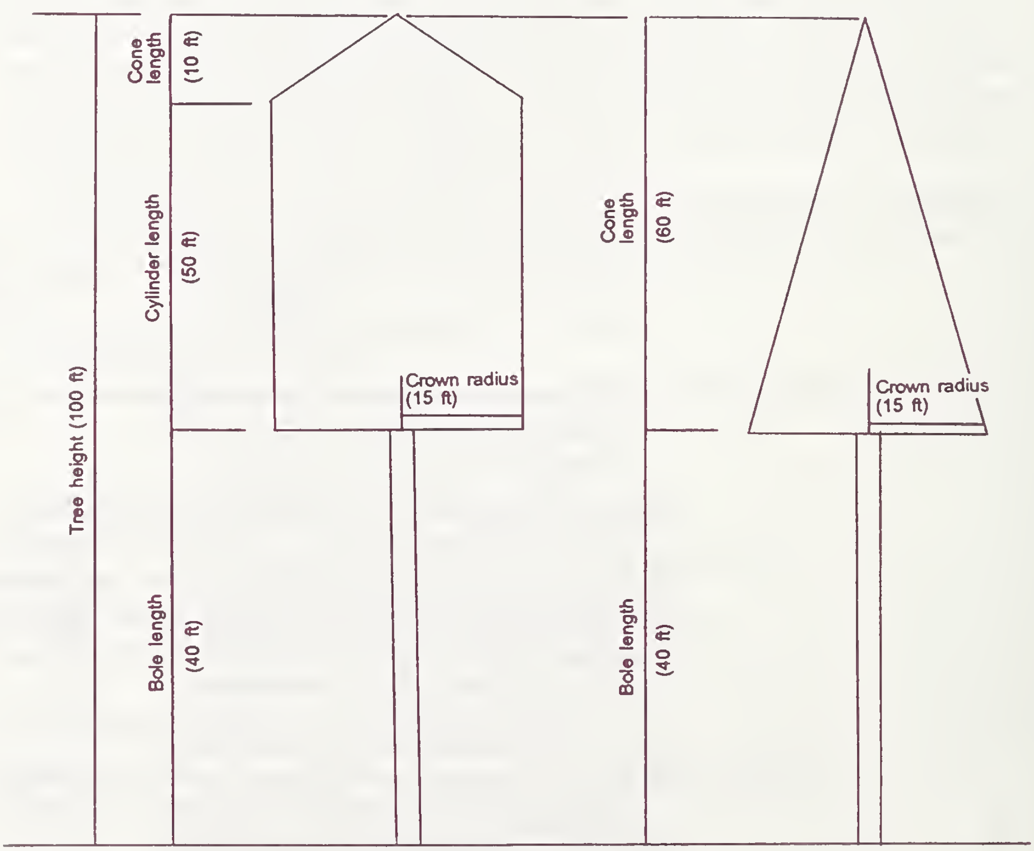


Figure 5—Tree variable definitions for developing tree length factors.

Table 4—Determining appropriate appendix from cone length percentage.

Cone length percentage	Latitude (degrees) 38	39	40	41	42	43	44	45	46	47	48
	Appendix										
0-10	E	E	E	E	E	E	E	E	E	E	E
10-20	E	E	E	E	E	E	E	E	E	E	E
20-30	E	E	E	E	E	E	E	F	F	F	F
>30	F	F	F	F	F	F	F	F	F	F	F

Step 5—Correct the tree length factor from appendix E

To most accurately determine the tree length factor from appendix E, correct it if the target tree does not have the same proportional form as the reference tree. To check the target tree's proportional form, calculate crown radius percentage from

$$\text{crown radius percent} = (\text{crown radius} / \text{total tree height}) \times 100 \qquad (2)$$

If the crown radius percentage (equation 2) does not equal 15 (the reference tree's crown radius percentage), find the cone length percent cutoff in appendix G by date. The cone length percent cutoff determines at what point along the tree's height the crown no longer intercepts the sun.

a. For June 21, locate the cone length percent cutoff in the boxed table by closest crown radius percentage and latitude.

b. For dates other than June 21:
   b1. Locate the crown radius percentage (equation 2) on the horizontal axis.
   b2. Follow up from the horizontal axis to the appropriate latitude line for even-numbered latitudes or halfway between for odd-numbered latitudes.
   b3. Read across to the cone length percent cutoff on the left vertical axis.

c. If the cone length percentage (equation 1) of the target tree is greater than the cone length percent cutoff from appendix G, then the crown radius correction (equation 3) is 0.00. (If this is the case, the tree length factor from appendix F is more appropriate than the tree length factor from appendix E.) If the target tree cone length percentage (equation 1) is less than the cone length percent cutoff from appendix G, then determine the crown radius correction from

$$\text{crown radius correction} = (\text{crown radius percent } [\text{equation 2}]/100) - 0.15 \qquad (3)$$

Add, if positive (or subtract, if negative) the crown radius correction (equation 3) to (or from) the tree length factor appendix E. This is the corrected tree length factor.

We developed the tree length factors for appendix E from a cylinder-shaped tree with a 15-foot crown radius (fig. 4). In many cases, correcting for crown radius may not significantly alter the tree length factor. However, suppressed trees with narrow crowns or open-grown trees with wide crowns may produce tree length factors much smaller or larger than uncorrected tree length factors. Experience with tree length factors in an area should help users determine when or if to correct for crown radius in different target stands.

Application

Tree length factors and shadow sweep information can be used to tailor tree marking to prescription requirements. Tree length factors can help silviculturists determine appropriate opening size and tree spacing to provide adequate shade for natural regeneration on sites where shade is deemed necessary. Silviculturists could take the shadow length information and combine it with data on daily, solar surface, and air temperatures, which reach their maximum between solar noon and 2 to 3 hours after solar noon (Fraser 1968; Hungerford and Babbitt 1987; Stathers and Spittlehouse 1990). Through the summer, air temperatures reach their maximum in July and August. The total shadow sweep angle shown in appendix D, divided by 2, provides the shadow azimuth 2 hours after solar noon for various dates through summer. Field personnel should be able to visualize critical season shadow patterns using a compass and tree length information no matter when tree marking takes place.

In most cases, once a tree length factor is determined for a tree form in a target stand, it remains the same as long as slope and aspect remain constant. Therefore, tree spacing or opening sizes will automatically adjust if tree heights change. For example, if the tree length factor is 50 percent stand height, completely shaded openings would be 50-feet wide for 100-foot tall overstory (100 feet x 0.50 = 50 feet) and 75-feet wide for 150-foot tall overstory (150 feet x 0.50 = 75 feet).

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Appendix A

Convert Solar Time to Local Time for June 21 at Any Location

1. Determine the site longitude (LS).
2. Determine the time meridian longitude (LM) for the time zone:
   a. Central time 90° W longitude
   b. Mountain time 105° W longitude
   c. Pacific time 120° W longitude
3. Determine the number of minutes to correct solar noon and longitude:

   Correction minutes = 4 minutes – (4 minutes/degree * [LM – LS]).
4. To determine solar noon, add (or subtract) the correction minutes from 12:00.
5. To correct for daylight savings time (if necessary), add 1 hour to the solar noon calculation.
6. This time is solar noon on June 21. Solar noon deviates 6 minutes earlier or 12 minutes later from May 10 through October 11.

Example Calculation

Convert solar noon to local time for Cascade, ID.

1. Cascade's longitude is 116° W.
2. The time meridian longitude for the time zone (mountain time) is 105° W longitude.
3. The correction minutes are:

   4 minutes – (4 minutes/° * [105° – 116°]) = 48 minutes.
4. Solar noon is 12:00 + 48 minutes = 12:48.
5. Correction for daylight savings time = 1 hour + 12:48 = 13:48.
6. This is solar noon at Cascade, ID, on June 21.

Appendix B

Worksheet for Deriving Tree Length Factor

Step 1—Target Stand Variables:

Location: ____________________

Latitude: ____________________ (see table 2)

Azimuth: ____________________ Aspect: ____________________

Slope: ________________________

Target date: __________________

Step 2—Average Tree Variables (see fig. 5 for definitions):

Tree height: _________________

Cone length: __________________

Crown radius: _________________

(Equation 1): Cone length percent = (cone length/tree height) x 100: ______________________

Step 3—Determine the Appropriate Appendix (use table 4 and cone length percentage from equation 1):

Appendix: ____________________

Step 4—Determine the Tree Length Factor (from appendix determined in step 3):

Tree length factor: ____________

Step 5—Correct the Tree Length Factor from Appendix E:

(Equation 2): Crown radius percent = (crown radius/ tree height) x 100: ___________

If the target tree **cone length percent** (equation 1), which = ___________ is greater than

the **cone length percent cutoff** (from appendix G), which = _________ then the crown radius correction (equation 3) = 0.00.

(If the crown radius correction = 0.00, use appendix F to determine the tree length factor.)

Otherwise, the crown radius correction =

(Equation 3) ((________)/100) – 0.15 = __________ .

(crown radius percent)
(Equation 2)

Final calculation:

______________	+	______________	=	______________
tree length factor		crown radius correction		corrected tree length factor

Example Calculation for Deriving Tree Length Factor

Step 1—Target Stand Variables:

Location: *East of Lewiston, Idaho*

Latitude: *47°* (see table 2)

Azimuth: *49°* *NE* Aspect: *NE*

Slope: *13° tan(13°) x100 = 23%*

Target date: *June 21*

Step 2—Average Tree Variables (see fig. 5 for definitions):

Tree height: *140 ft*

Cone length: *24 ft*

Crown radius: *32 ft*

(Equation 1): Cone length percent = (cone length/tree height) x 100: *(24/140) x100 = 17%*

Step 3—Determine the Appropriate Appendix (use table 4 and cone length percentage from equation 1):

Appendix: *E*

Step 4—Determine the Tree Length Factor (from appendix determined in step 3):

Tree length factor: *0.60*

Step 5—Correct the Tree Length Factor from Appendix E:

(Equation 2): Crown radius percent = (crown radius/ tree height) x 100: *(32/140) x100 = 23*

If the target tree **cone length percent** (equation 1), which = *17* is greater than

the **cone length percent cutoff** (from appendix G), which = *35-* *46* (*crown radius*): *15%* *20%*
then the crown radius correction (equation 3) = 0.00.

(If the crown radius correction = 0.00, use appendix F to determine the tree length factor.)

Otherwise, the crown radius correction =

(Equation 3) ((*23*)/100) – 0.15 = *+0.08* .

(crown radius percent)
(Equation 2)

Final calculation:

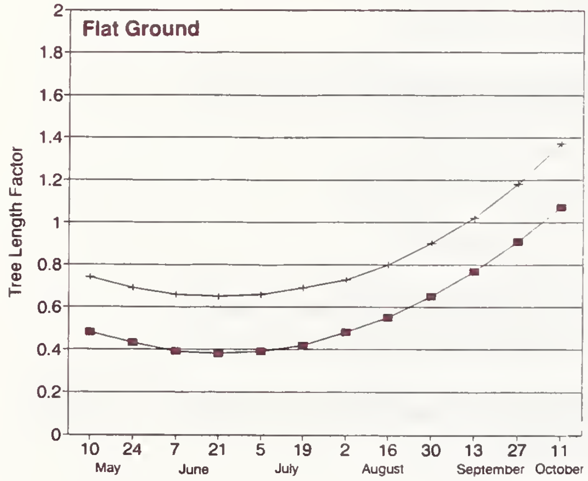
0.60		*+0.08*		*0.68*
tree length factor	+	crown radius correction	=	corrected tree length factor

Appendix C

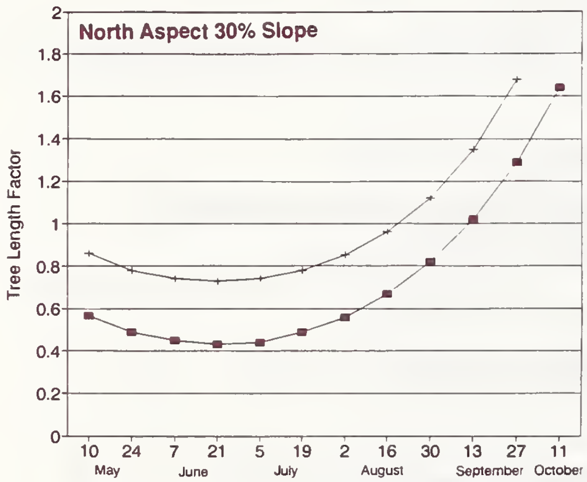
Latitude 38°

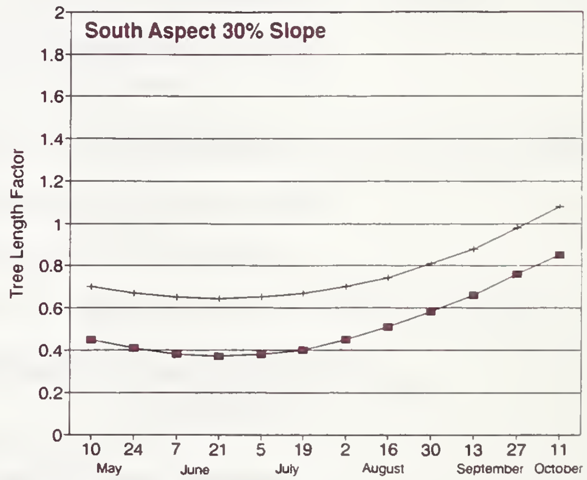
Reference area: 13 miles north of Panguitch, 9 miles north of Monticello, UT

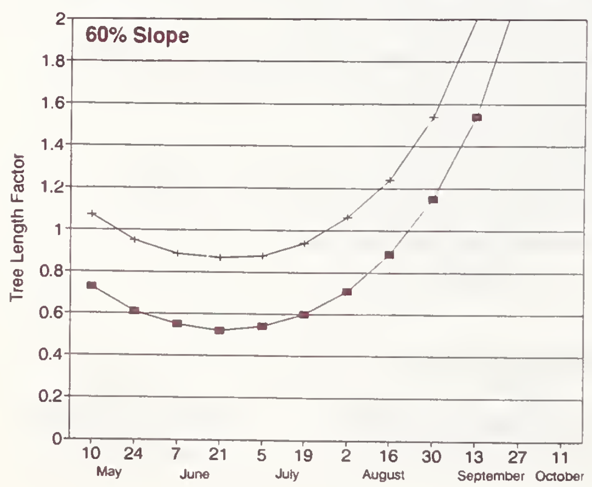
Tree length factors for cylinder-shaped trees at solar noon (Time 0°) and 2 hours before and after solar noon (Time ± 30°) from May 10 through October 11.

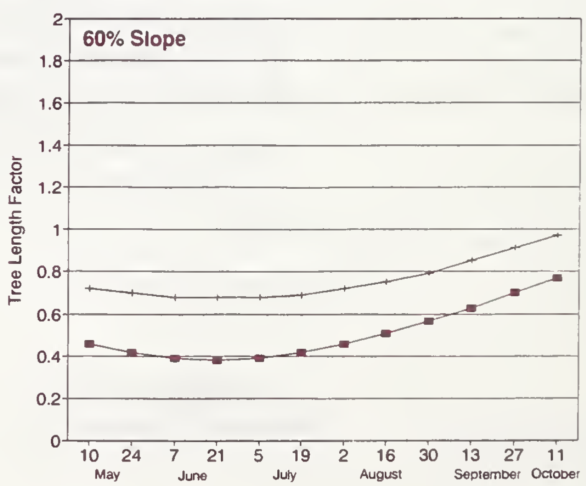


Shortest shadow June 21 at solar noon	
Location	**Length**
Flat ground	0.38
North aspect	
15% slope	0.40
30% slope	0.43
45% slope	0.47
60% slope	0.52
South aspect	
15% slope	0.37
30% slope	0.37
45% slope	0.37
60% slope	0.38







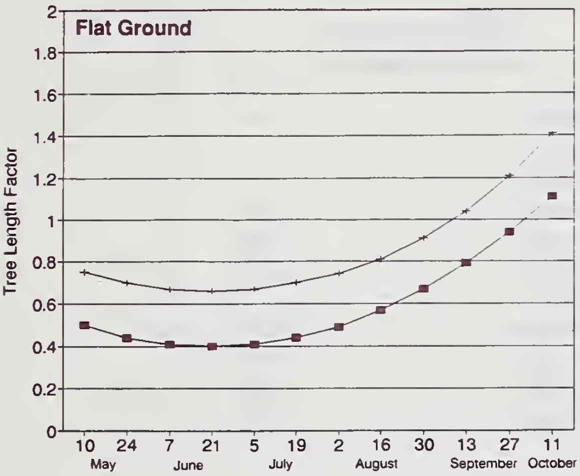


—■— Time 0 —+— Time ± 30

Latitude 39°

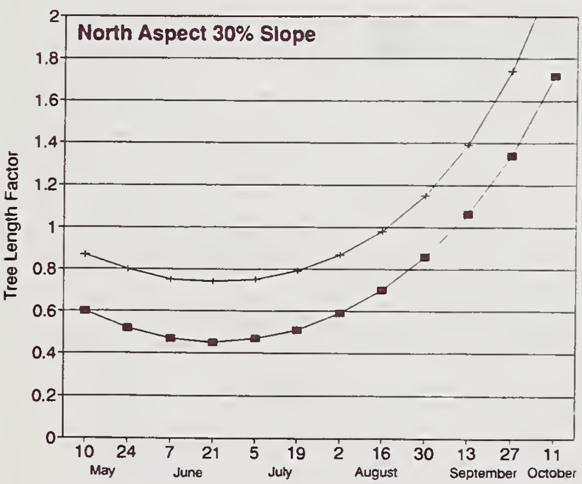
Reference area: 3 miles north of Fillmore, at Green River, UT

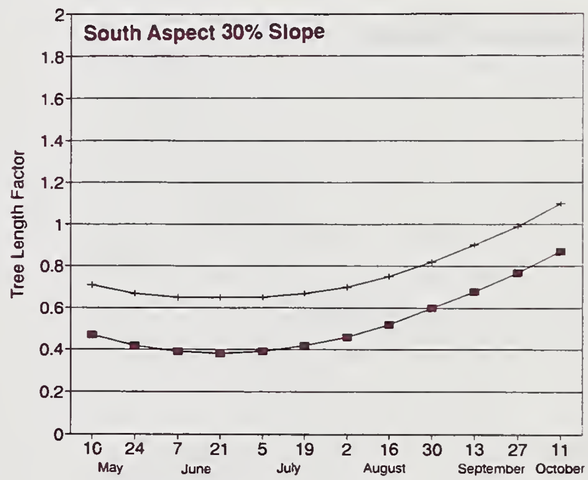
Tree length factors for cylinder-shaped trees at solar noon (Time 0°) and 2 hours before and after solar noon (Time ± 30°) from May 10 through October 11.

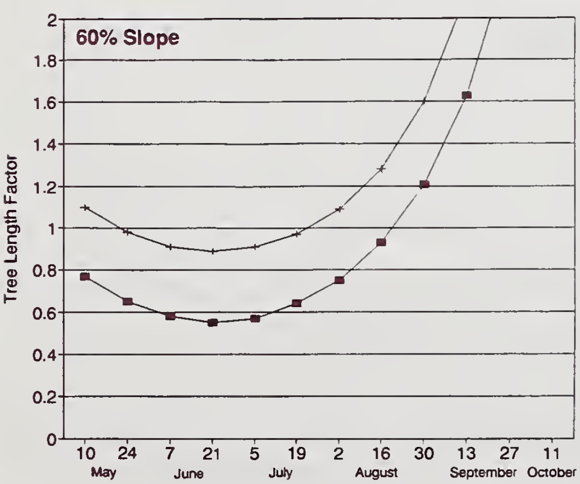


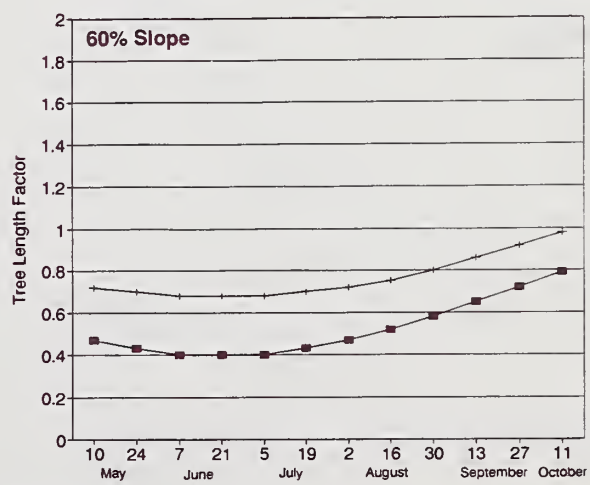
Shortest shadow
June 21 at solar noon

Location	Length
Flat ground	0.40
North aspect	
15% slope	0.42
30% slope	0.45
45% slope	0.49
60% slope	0.55
South aspect	
15% slope	0.38
30% slope	0.38
45% slope	0.39
60% slope	0.40







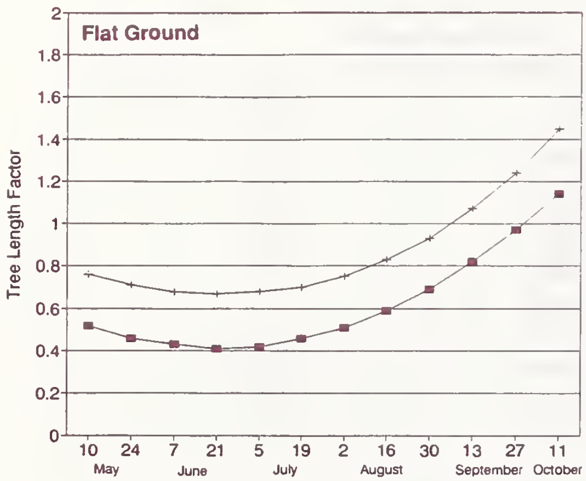


–■– Time 0 —+— Time ± 30

Latitude 40°

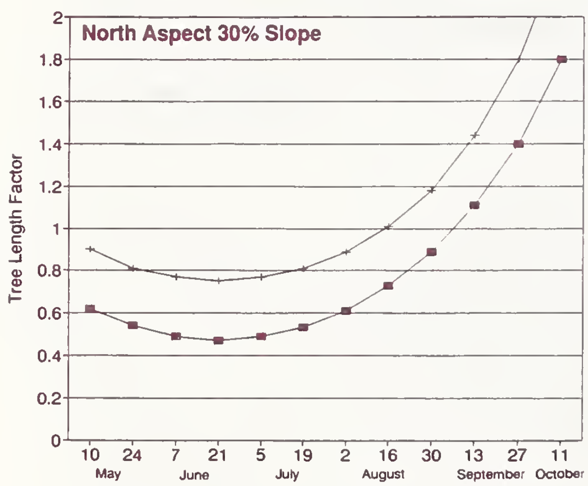
Reference area: 14 miles south of Provo, 30 miles south of Vernal, UT

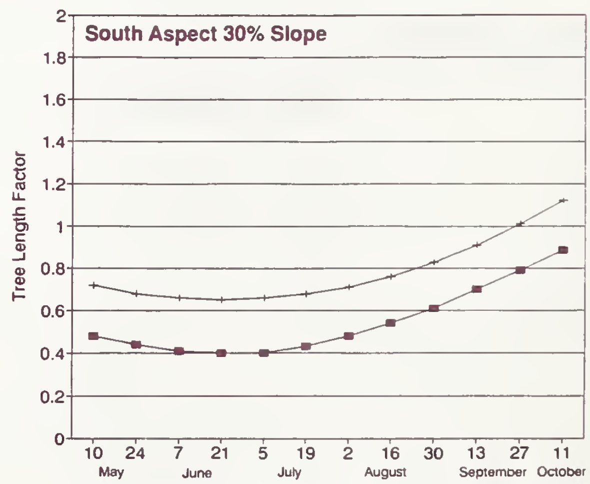
Tree length factors for cylinder-shaped trees at solar noon (Time 0°) and 2 hours before and after solar noon (Time ± 30°) from May 10 through October 11.

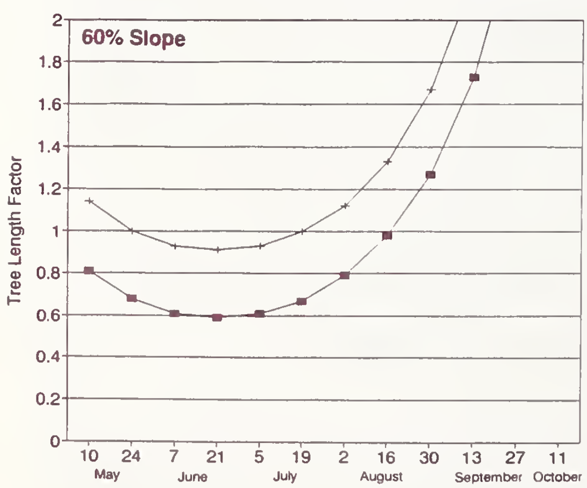


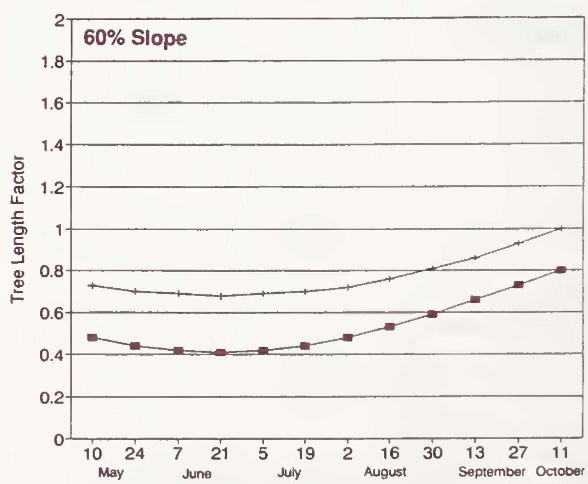
Shortest shadow
June 21 at solar noon

Location	Length
Flat ground	0.41
North aspect	
15% slope	0.44
30% slope	0.47
45% slope	0.52
60% slope	0.59
South aspect	
15% slope	0.40
30% slope	0.40
45% slope	0.40
60% slope	0.41







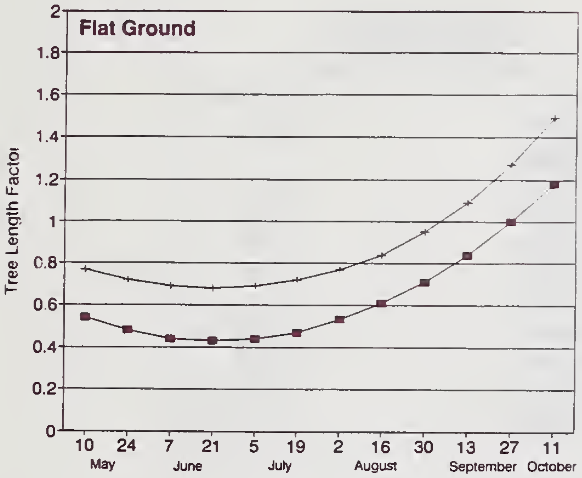


Time 0   Time ± 30

Latitude 41°

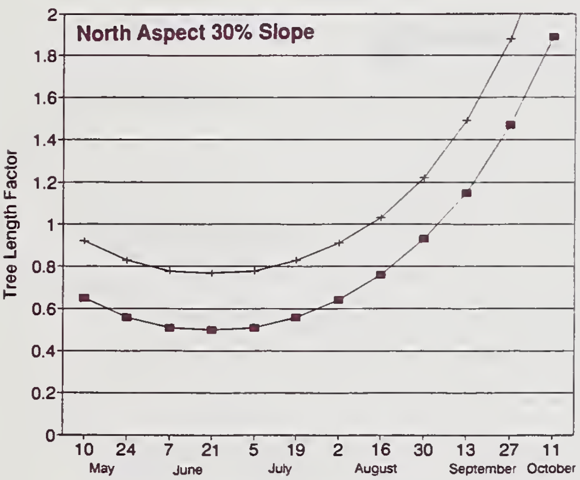
Reference area: 13 miles north of Salt Lake City, 16 miles south of Ogden, UT

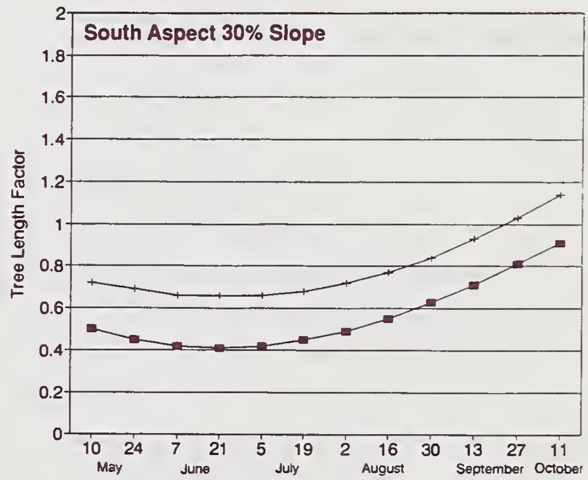
Tree length factors for cylinder-shaped trees at solar noon (Time 0°) and 2 hours before and after solar noon (Time ± 30°) from May 10 through October 11.

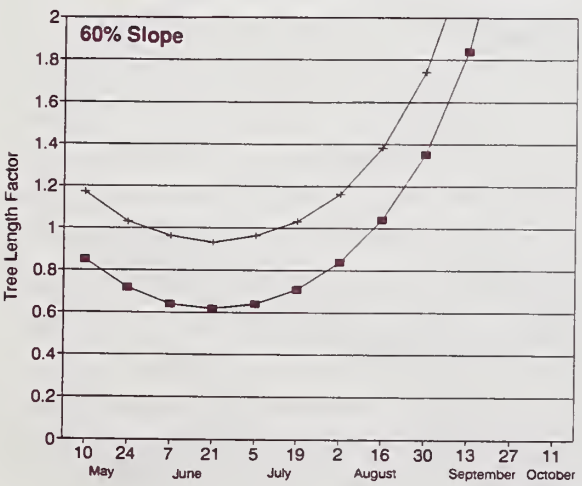


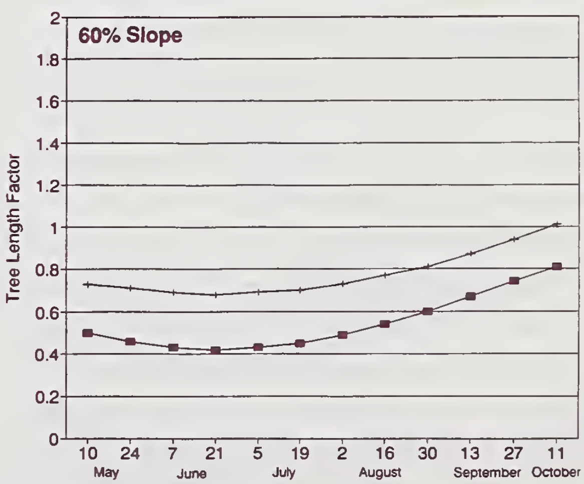
Shortest shadow
June 21 at solar noon

Location	Length
Flat ground	0.43
North aspect	
15% slope	0.46
30% slope	0.50
45% slope	0.55
60% slope	0.62
South aspect	
15% slope	0.41
30% slope	0.41
45% slope	0.41
60% slope	0.42







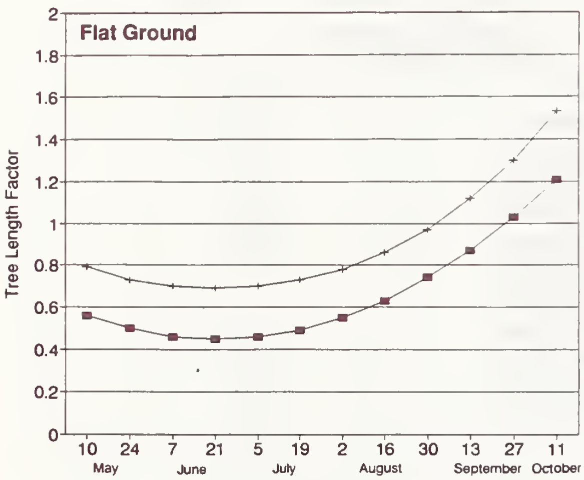


—■— Time 0 —+— Time ± 30

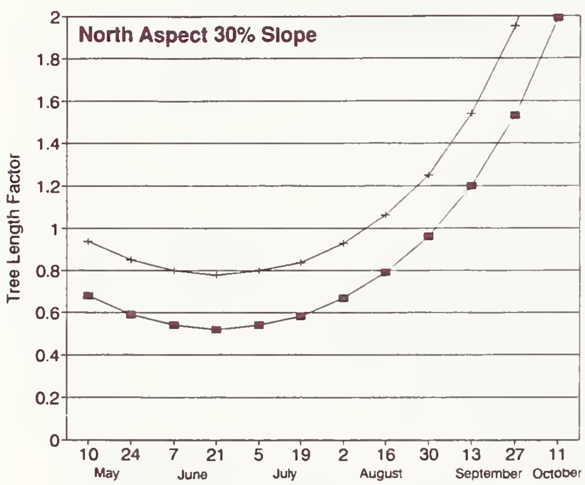
Latitude 42°

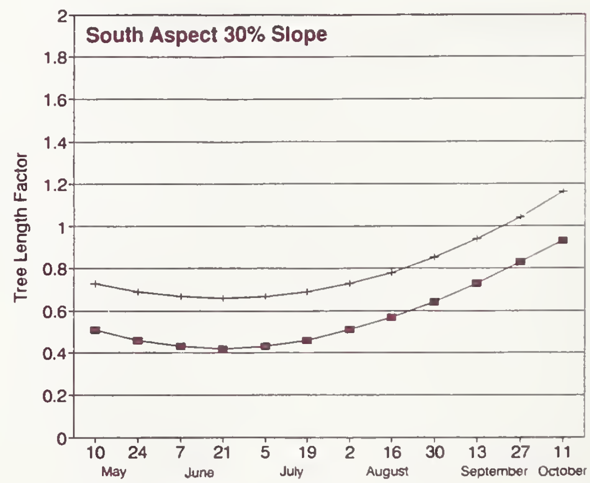
Reference area: Border between Utah and Idaho

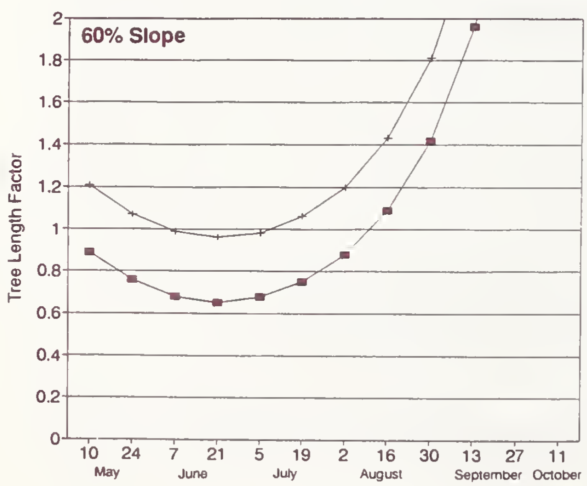
Tree length factors for cylinder-shaped trees at solar noon (Time 0°) and 2 hours before and after solar noon (Time ± 30°) from May 10 through October 11.

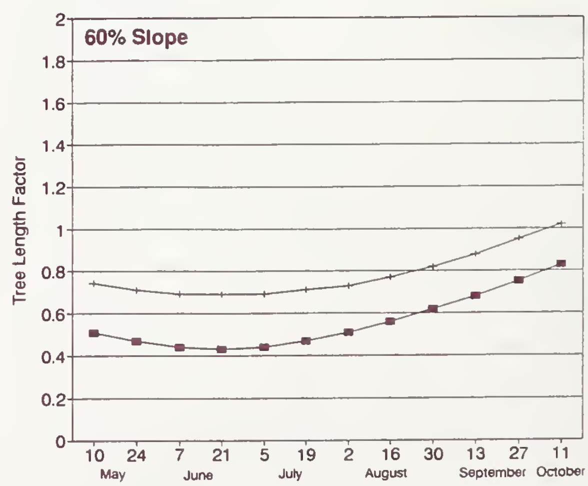


Shortest shadow June 21 at solar noon	
Location	**Length**
Flat ground	0.45
North aspect	
15% slope	0.48
30% slope	0.52
45% slope	0.58
60% slope	0.65
South aspect	
15% slope	0.43
30% slope	0.42
45% slope	0.43
60% slope	0.43







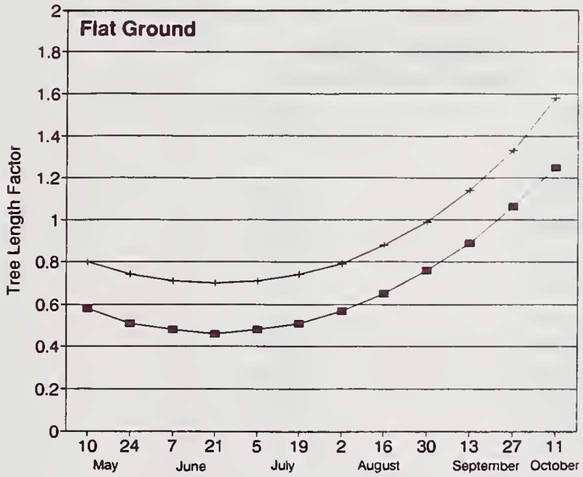


Time 0 Time ± 30

Latitude 43°

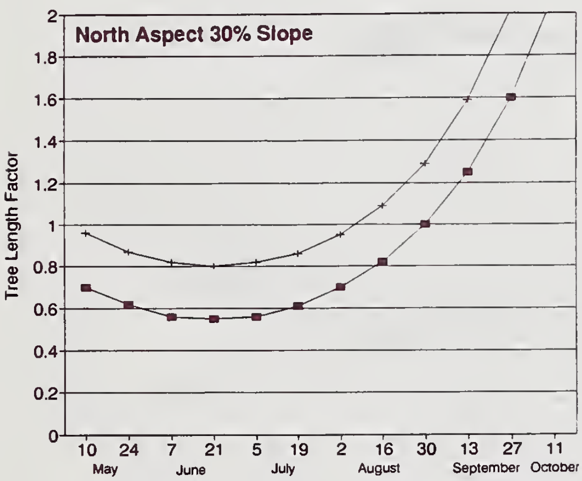
Reference area: at Glenns Ferry, 12 miles north of Pocatello, ID

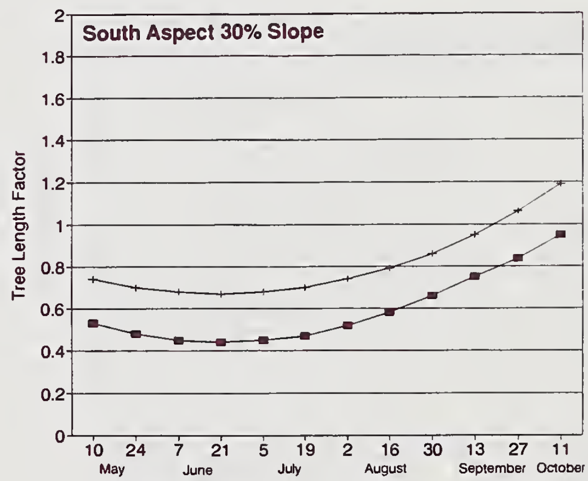
Tree length factors for cylinder-shaped trees at solar noon (Time 0°) and 2 hours before and after solar noon (Time ± 30°) from May 10 through October 11.

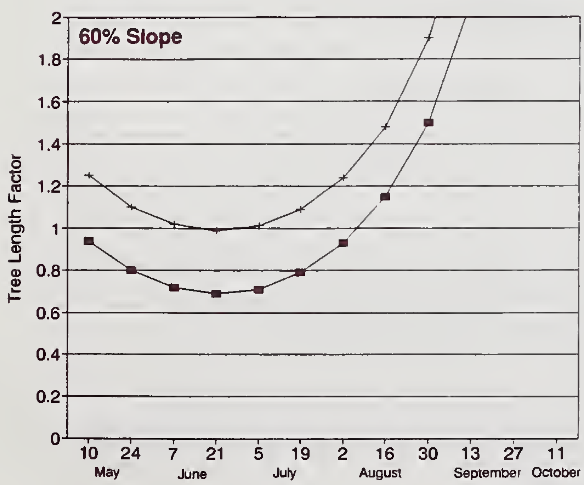


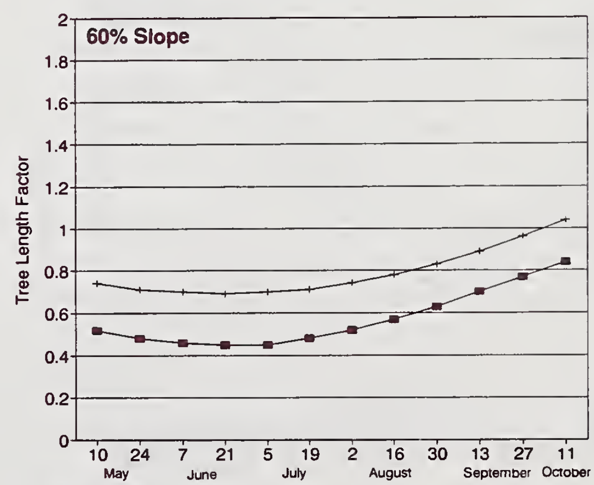
Shortest shadow
June 21 at solar noon

Location	Length
Flat ground	0.46
North aspect	
15% slope	0.50
30% slope	0.55
45% slope	0.60
60% slope	0.69
South aspect	
15% slope	0.45
30% slope	0.44
45% slope	0.44
60% slope	0.45







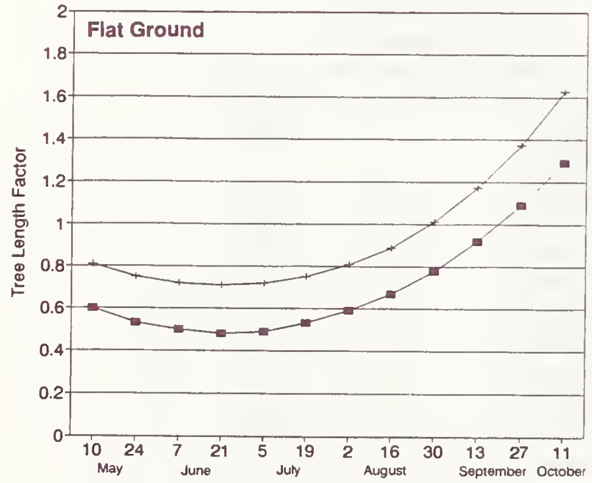


—■— Time 0 —+— Time ± 30

Latitude 44°

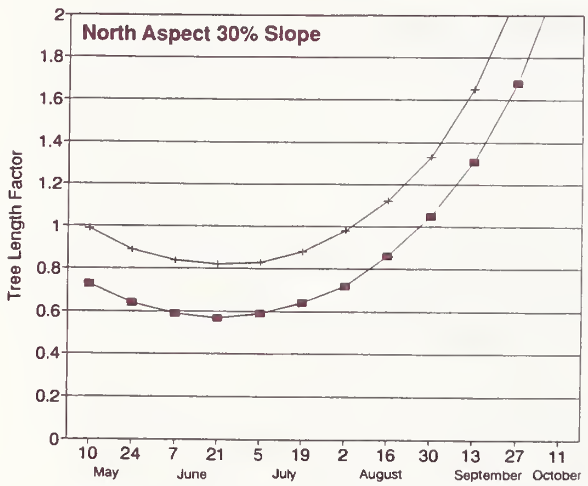
Reference area: 5 miles north of Horseshoe Bend, 2 miles north of St. Anthony, ID

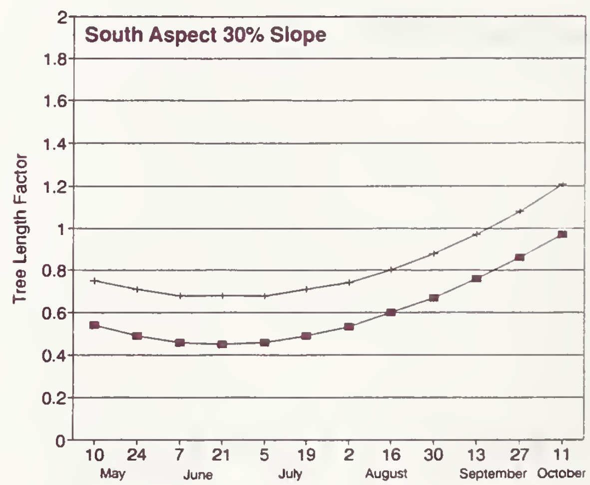
Tree length factors for cylinder-shaped trees at solar noon (Time 0°) and 2 hours before and after solar noon (Time ± 30°) from May 10 through October 11.

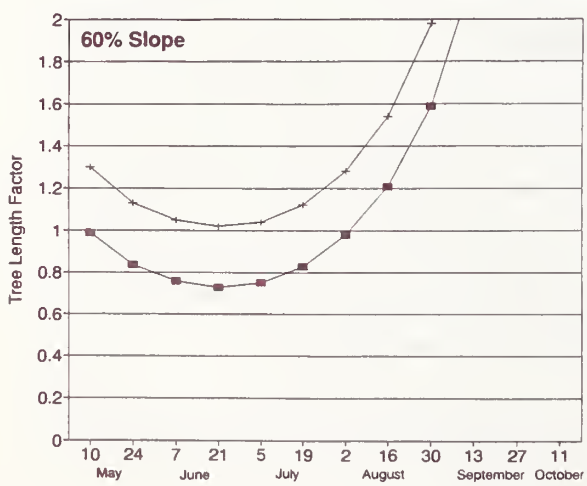


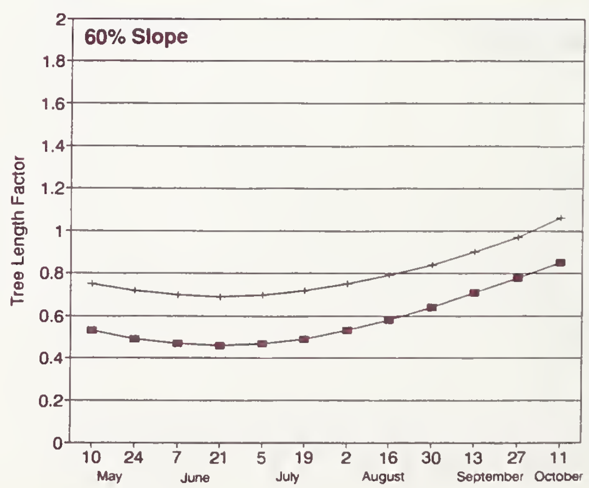
Shortest shadow
June 21 at solar noon

Location	Length
Flat ground	0.48
North aspect	
15% slope	0.52
30% slope	0.57
45% slope	0.63
60% slope	0.73
South aspect	
15% slope	0.46
30% slope	0.45
45% slope	0.45
60% slope	0.45







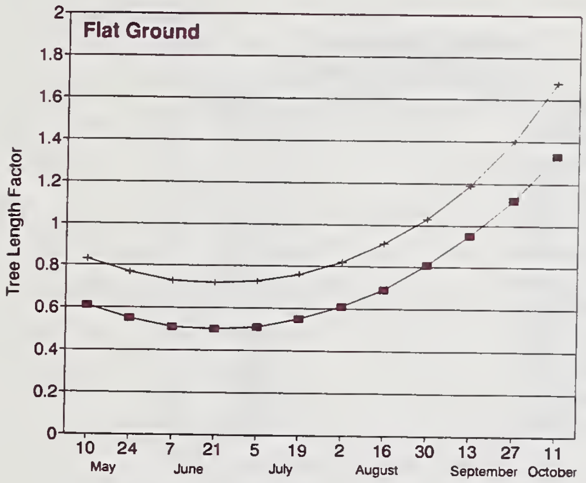


—■— Time 0 —+— Time ± 30

Latitude 45°

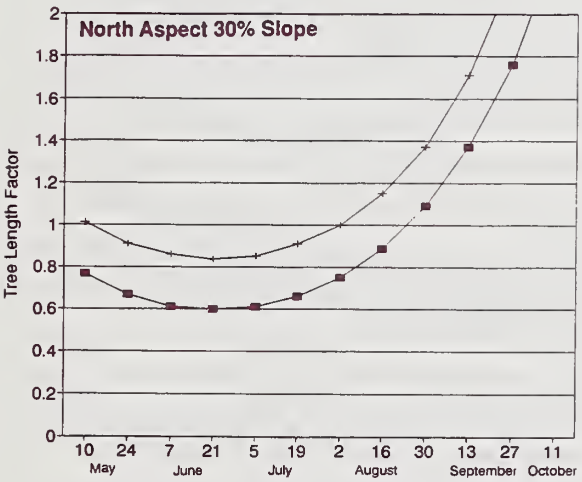
Reference area: 1.5 miles north of New Meadows, 9 miles south of Salmon, ID

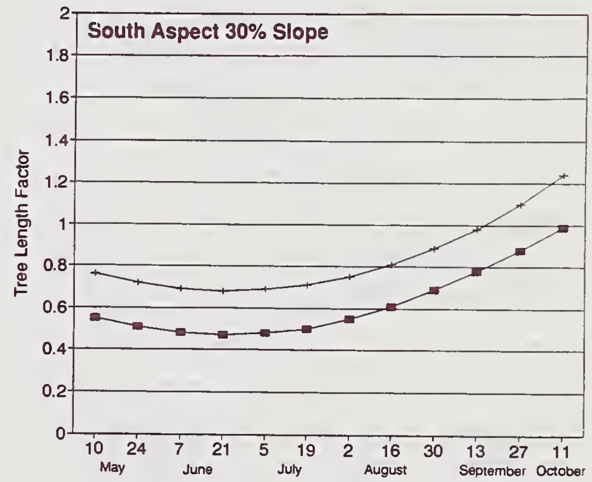
Tree length factors for cylinder-shaped trees at solar noon (Time 0°) and 2 hours before and after solar noon (Time ± 30°) from May 10 through October 11.

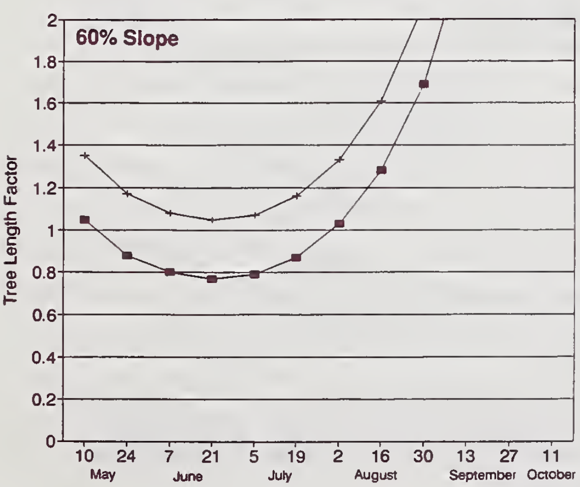


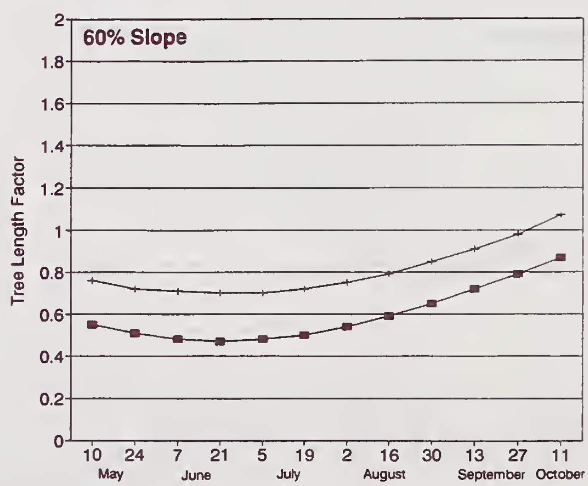
Shortest shadow
June 21 at solar noon

Location	Length
Flat ground	0.50
North aspect	
15% slope	0.54
30% slope	0.60
45% slope	0.66
60% slope	0.77
South aspect	
15% slope	0.48
30% slope	0.47
45% slope	0.47
60% slope	0.47







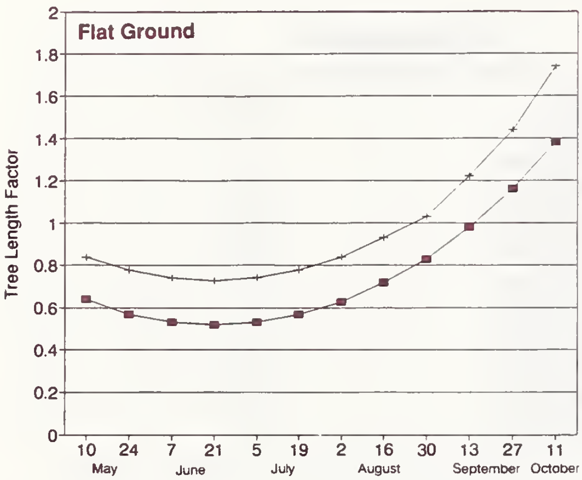


—■— Time 0 —+— Time ± 30

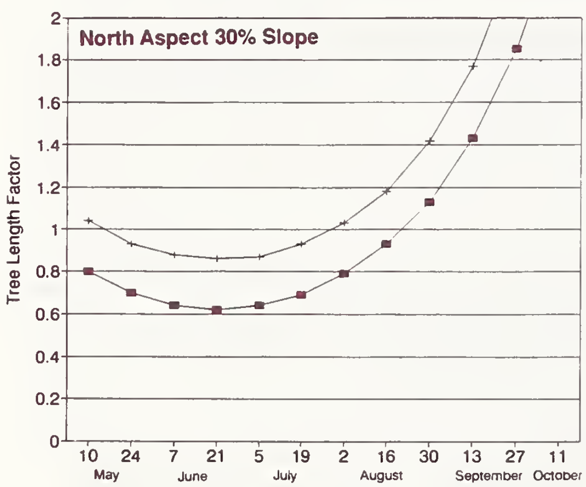
Latitude 46°

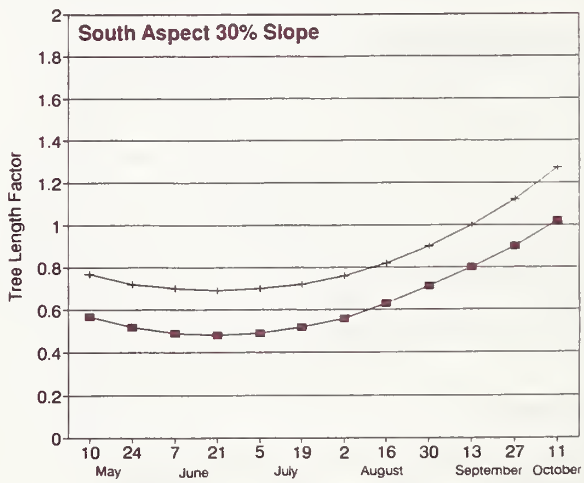
Reference area: 5 miles north of Grangeville, ID

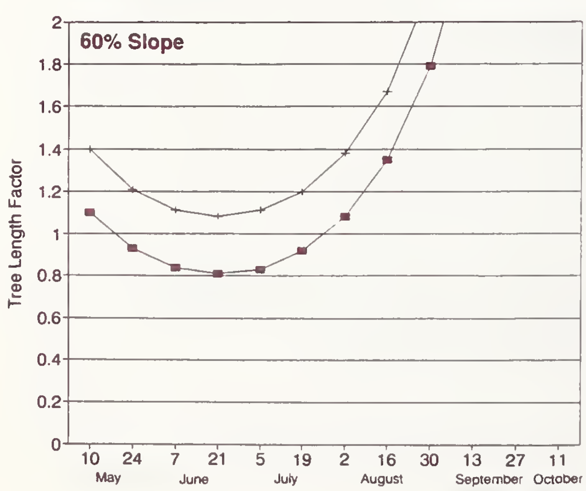
Tree length factors for cylinder-shaped trees at solar noon (Time 0°) and 2 hours before and after solar noon (Time ± 30°) from May 10 through October 11.

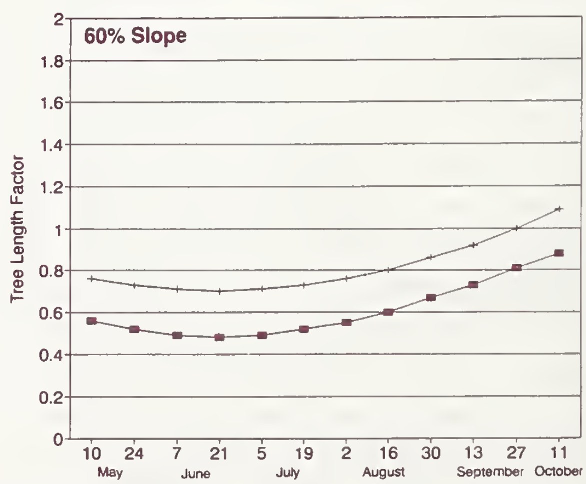


Shortest shadow June 21 at solar noon	
Location	**Length**
Flat ground	0.52
North aspect	
15% slope	0.56
30% slope	0.62
45% slope	0.70
60% slope	0.81
South aspect	
15% slope	0.49
30% slope	0.48
45% slope	0.48
60% slope	0.48







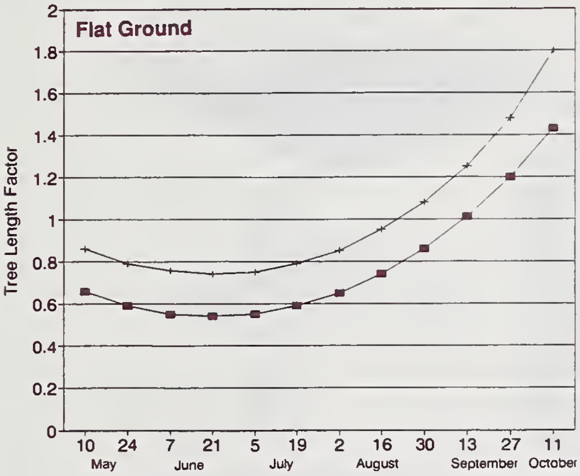


—■— Time 0 —+— Time ± 30

Latitude 47°

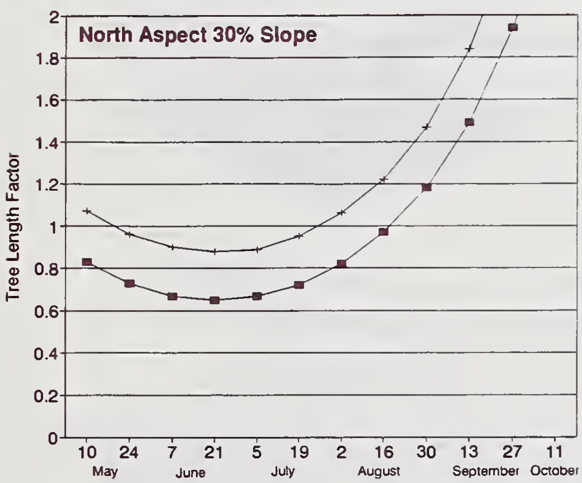
Reference area: 6 miles north of Boville, 2 miles south of Clarkia, ID

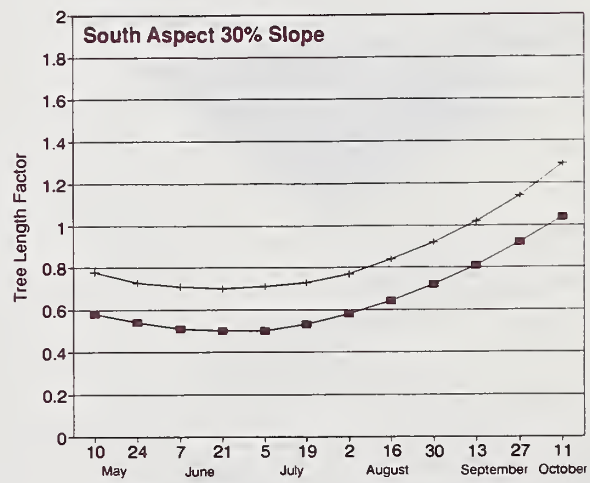
Tree length factors for cylinder-shaped trees at solar noon (Time 0°) and 2 hours before and after solar noon (Time ± 30°) from May 10 through October 11.

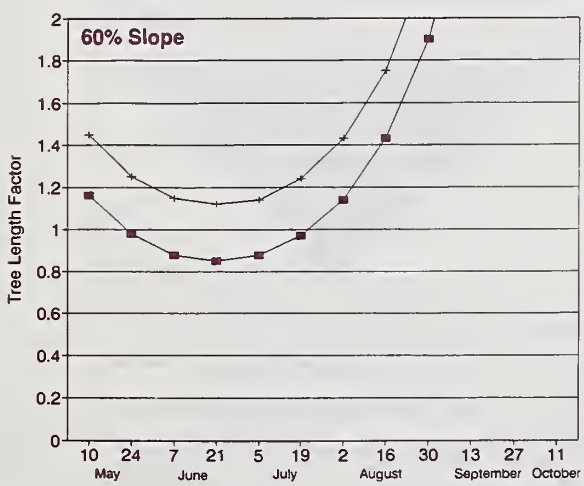


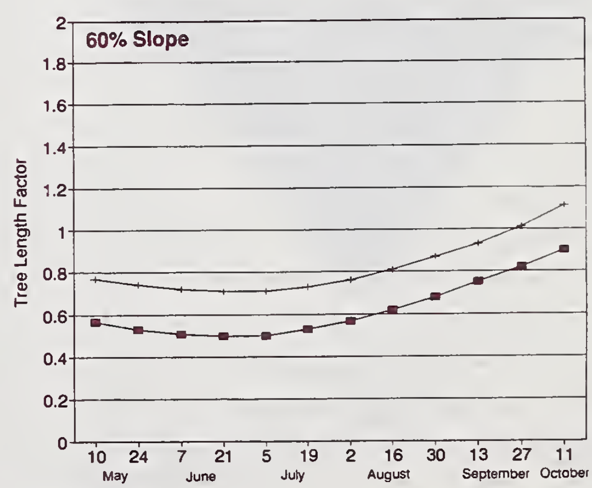
Shortest shadow
June 21 at solar noon

Location	**Length**
Flat ground	0.54
North aspect	
15% slope	0.58
30% slope	0.65
45% slope	0.73
60% slope	0.85
South aspect	
15% slope	0.51
30% slope	0.50
45% slope	0.49
60% slope	0.50







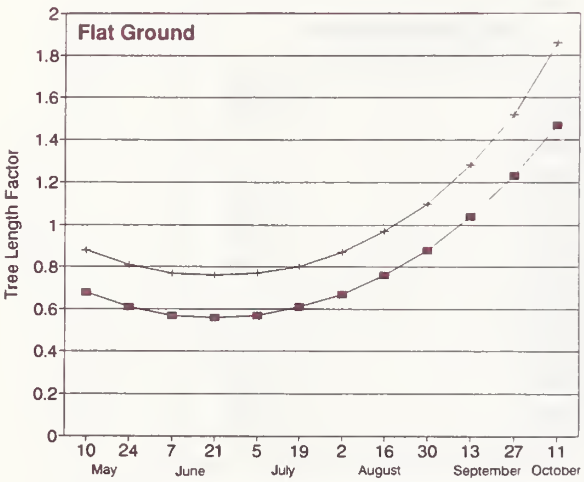


Time 0 Time ± 30

Latitude 48°

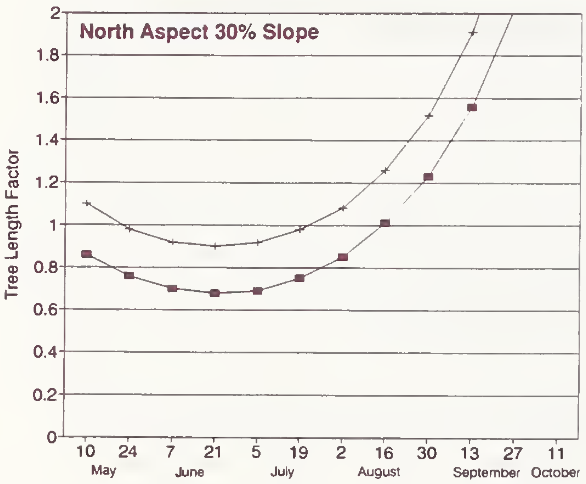
Reference area: 20 miles north of Coeur d'Alene, ID

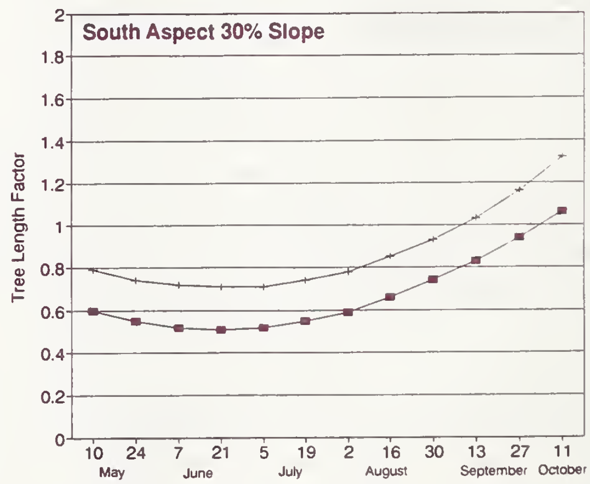
Tree length factors for cylinder-shaped trees at solar noon (Time 0°) and 2 hours before and after solar noon (Time ± 30°) from May 10 through October 11.

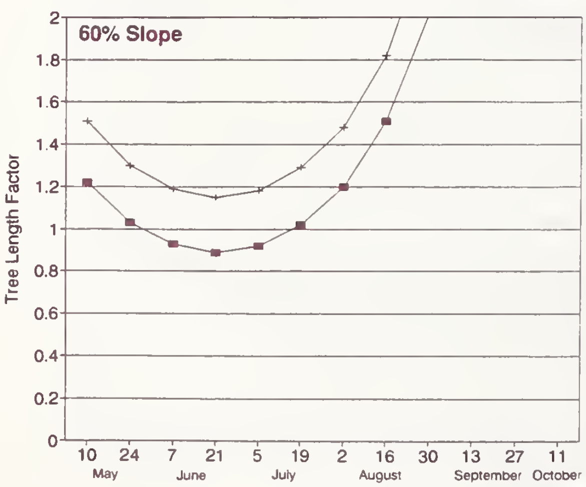


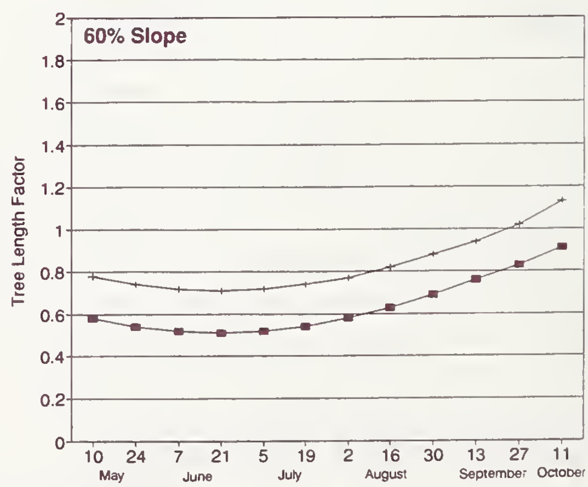
Shortest shadow
June 21 at solar noon

Location	Length
Flat ground	0.56
North aspect	
15% slope	0.61
30% slope	0.68
45% slope	0.76
60% slope	0.89
South aspect	
15% slope	0.53
30% slope	0.51
45% slope	0.51
60% slope	0.51









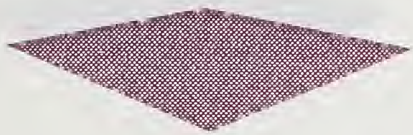
Time 0 Time ± 30

Appendix D

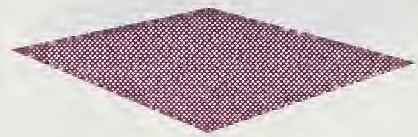
Latitude 38°

Reference area: 13 miles north of Panguitch, 9 miles north of Monticello, UT

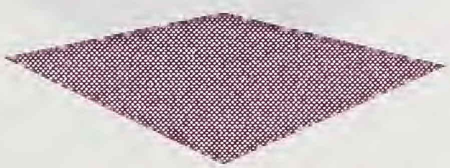
Shadow sweep angle for flat ground enclosed by shadow azimuth and shadow length for cylinder-shaped trees at solar noon and 2 hours before and 2 hours after solar noon.



May 24
Total angle: 129.4°



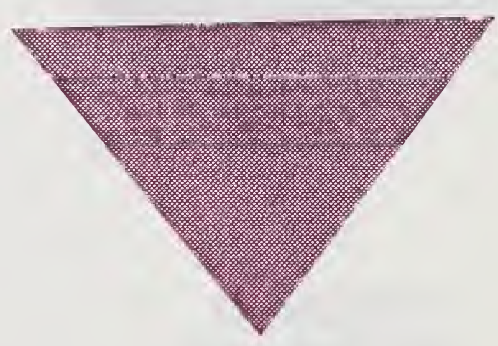
June 21
Total angle: 138.2°



July 19
Total angle: 130.2°

August 16
Total angle: 111.2°

September 13
Total angle: 91.2°

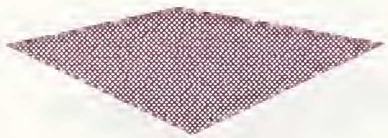


October 11
Total angle: 75.8°

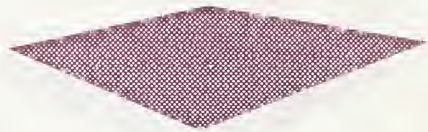
Latitude 39°

Reference area: 3 miles north of Fillmore, at Green River, UT

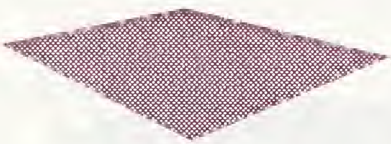
Shadow sweep angle for flat ground enclosed by shadow azimuth and shadow length for cylinder-shaped trees at solar noon and 2 hours before and 2 hours after solar noon.



May 24
Total angle: 126.6°



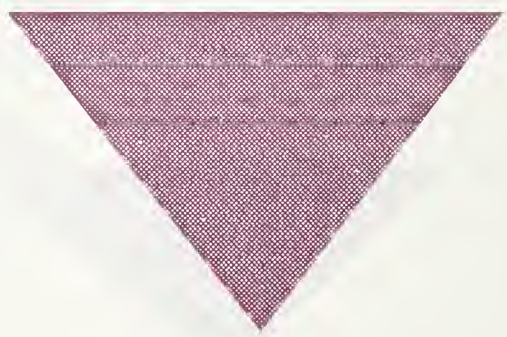
June 21
Total angle: 134.8°



July 19
Total angle: 127.2°

August 16
Total angle: 109.0°

September 13
Total angle: 89.8°

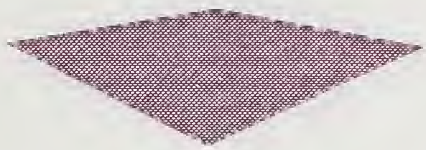


October 11
Total angle: 75.0°

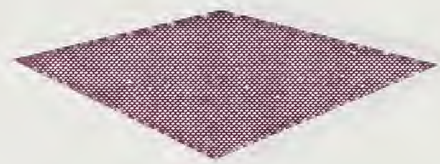
Latitude 40°

Reference area: 14 miles south of Provo, 30 miles south of Vernal, UT

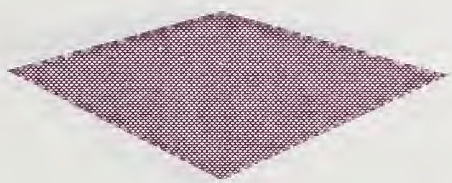
Shadow sweep angle for flat ground enclosed by shadow azimuth and shadow length for cylinder-shaped trees at solar noon and 2 hours before and 2 hours after solar noon.



May 24
Total angle: 123.6°

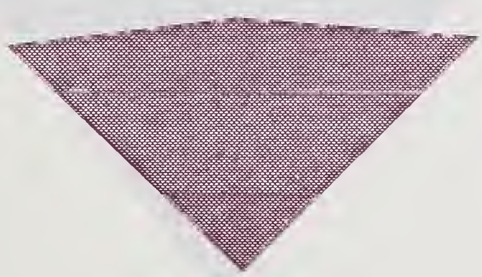


June 21
Total angle: 131.6°



July 19
Total angle: 124.4°

August 16
Total angle: 106.8°



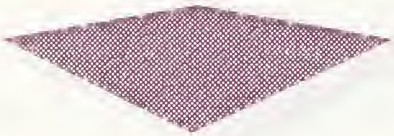
September 13
Total angle: 88.4°

October 11
Total angle: 74.0°

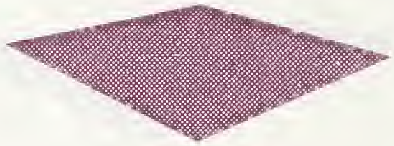
Latitude 41°

Reference area: 13 miles north of Salt Lake City, 16 miles south of Ogden, UT

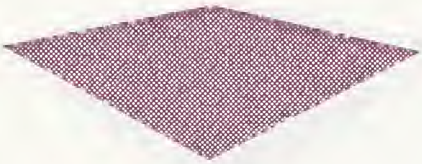
Shadow sweep angle for flat ground enclosed by shadow azimuth and shadow length for cylinder-shaped trees at solar noon and 2 hours before and 2 hours after solar noon.



May 24
Total angle: 121.0°

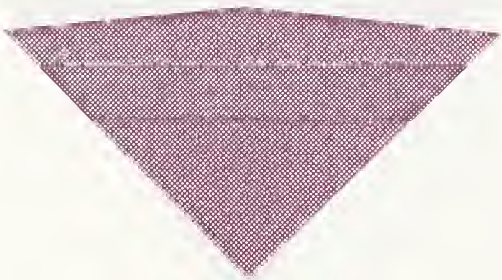


June 21
Total angle: 128.6°



July 19
Total angle: 121.6°

August 16
Total angle: 104.8°



September 13
Total angle: 87.2°

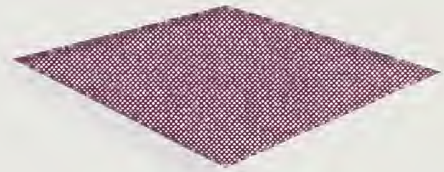
October 11
Total angle: 73.2°

Latitude 42°

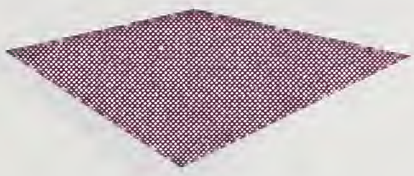
Reference area: 14 miles south of Provo, 30 miles south of Vernal, UT

Shadow sweep angle for flat ground enclosed by shadow azimuth and shadow length for cylinder-shaped trees at solar noon and 2 hours before and 2 hours after solar noon.

May 24
Total angle: 118.2°



June 21
Total angle: 125.6°



July 19
Total angle: 118.8°

August 16
Total angle: 102.8°

September 13
Total angle: 85.8°

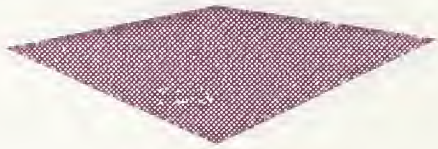
October 11
Total angle: 72.4°

Latitude 43°

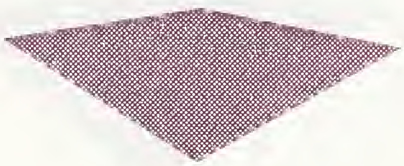
Reference area: at Glenns Ferry, 12 miles north of Pocatello, ID

Shadow sweep angle for flat ground enclosed by shadow azimuth and shadow length for cylinder-shaped trees at solar noon and 2 hours before and 2 hours after solar noon.

May 24
Total angle: 115.6°

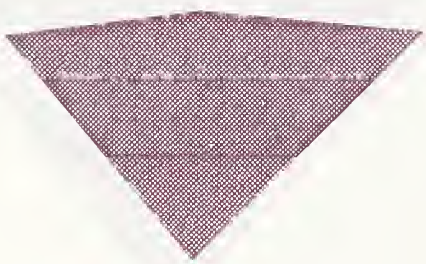


June 21
Total angle: 122.6°



July 19
Total angle: 116.2°

August 16
Total angle: 100.8°



September 13
Total angle: 84.6°

October 11
Total angle: 71.8°

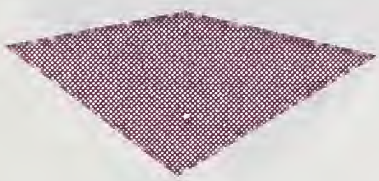
Latitude 44°

Reference area: 5 miles north of Horseshoe Bend, 2 miles north of St. Anthony, ID

Shadow sweep angle for flat ground enclosed by shadow azimuth and shadow length for cylinder-shaped trees at solar noon and 2 hours before and 2 hours after solar noon.

May 24
Total angle: 113.2°

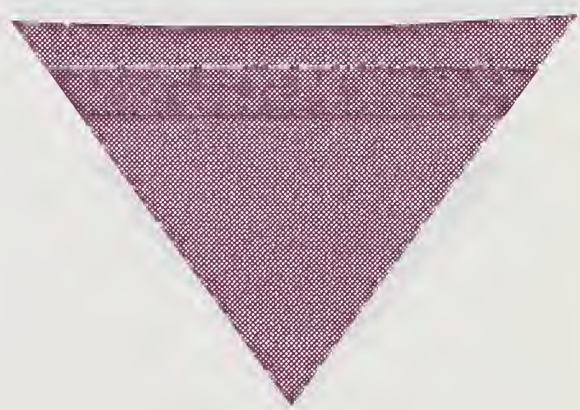
June 21
Total angle: 119.8°



July 19
Total angle: 113.6°

August 16
Total angle: 99.0°

September 13
Total angle: 83.4°



October 11
Total angle: 71.0°

Latitude 45°

Reference area: 1.5 miles north of New Meadows, 9 miles south of Salmon, ID

Shadow sweep angle for flat ground enclosed by shadow azimuth and shadow length for cylinder-shaped trees at solar noon and 2 hours before and 2 hours after solar noon.

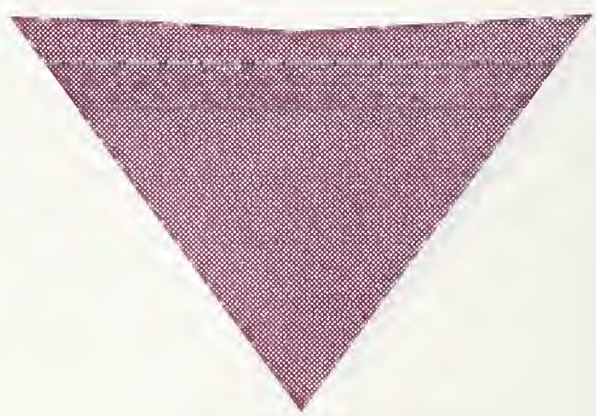
May 24
Total angle: 110.8°

June 21
Total angle: 117.2°

July 19
Total angle: 111.2°

August 16
Total angle: 97.2°

September 13
Total angle: 82.2°



October 11
Total angle: 70.2°

Latitude 46°

Reference area: 5 miles north of Grangeville, ID

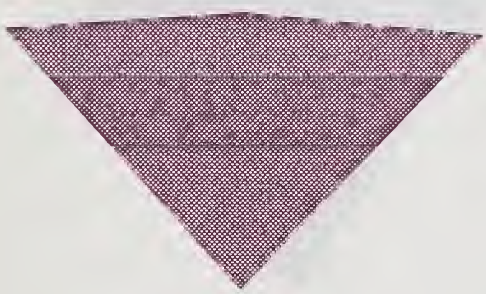
Shadow sweep angle for flat ground enclosed by shadow azimuth and shadow length for cylinder-shaped trees at solar noon and 2 hours before and 2 hours after solar noon.

May 24
Total angle: 108.4°

June 21
Total angle: 114.4°

July 19
Total angle: 108.8°

August 16
Total angle: 95.4°



September 13
Total angle: 81.2°

October 11
Total angle: 69.6°

Latitude 47°

Reference area: 6 miles north of Boville, 2 miles south of Clarkia, ID

Shadow sweep angle for flat ground enclosed by shadow azimuth and shadow length for cylinder-shaped trees at solar noon and 2 hours before and 2 hours after solar noon.

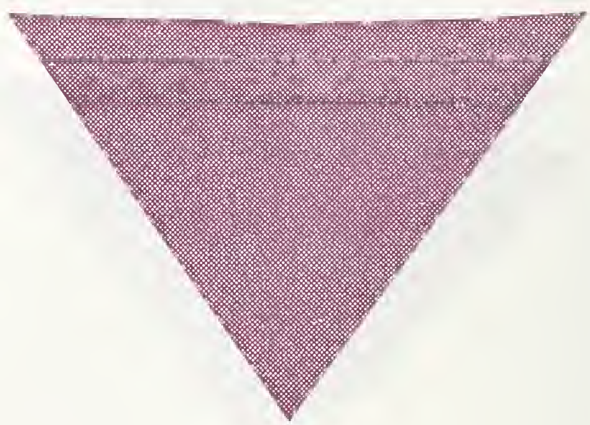
May 24
Total angle: 106.2°

June 21
Total angle: 112.0°

July 19
Total angle: 106.6°

August 16
Total angle: 93.8°

September 13
Total angle: 80.2°



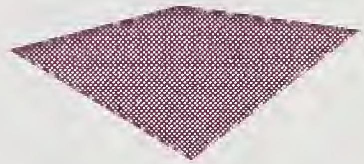
October 11
Total angle: 69.0°

Latitude 48°

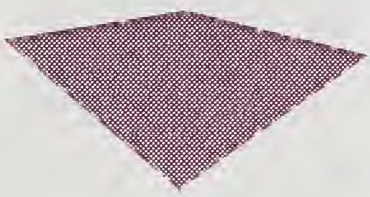
Reference area: 20 miles north of Coeur d'Alene, ID

Shadow sweep angle for flat ground enclosed by shadow azimuth and shadow length for cylinder-shaped trees at solar noon and 2 hours before and 2 hours after solar noon.

May 24
Total angle: 104.0°



June 21
Total angle: 109.6°



July 19
Total angle: 104.4°

August 16
Total angle: 92.2°

September 13
Total angle: 79.0°

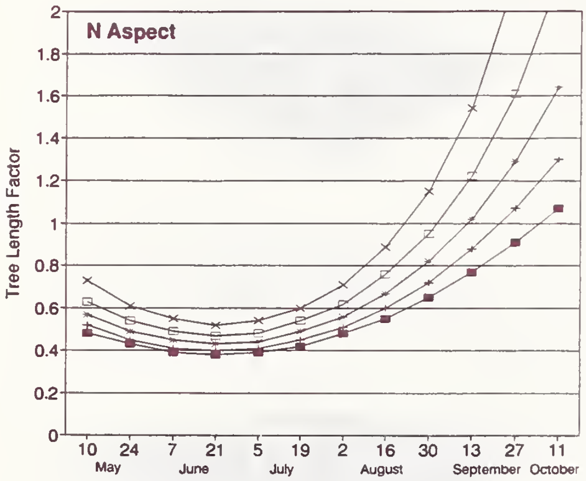
October 11
Total angle: 68.4°

Appendix E

Latitude 38°

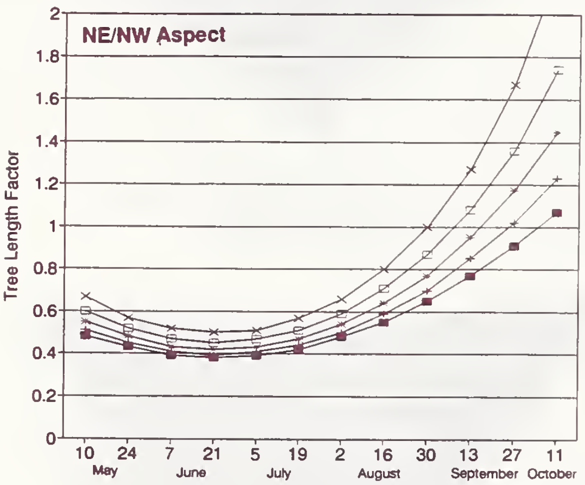
Reference area: 13 miles north of Panguitch, 9 miles north of Monticello, UT

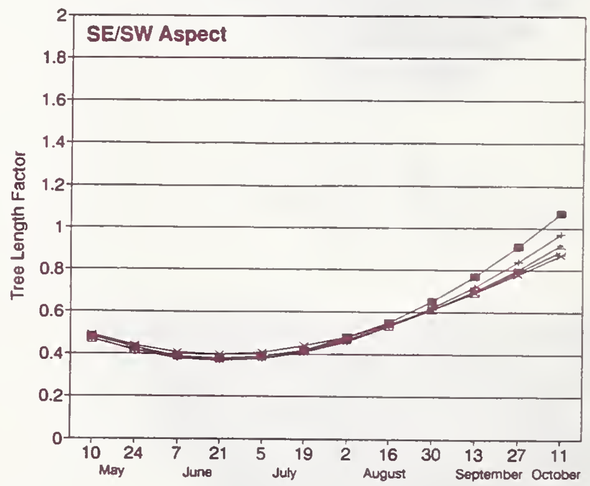
Tree length factors for cylinder-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

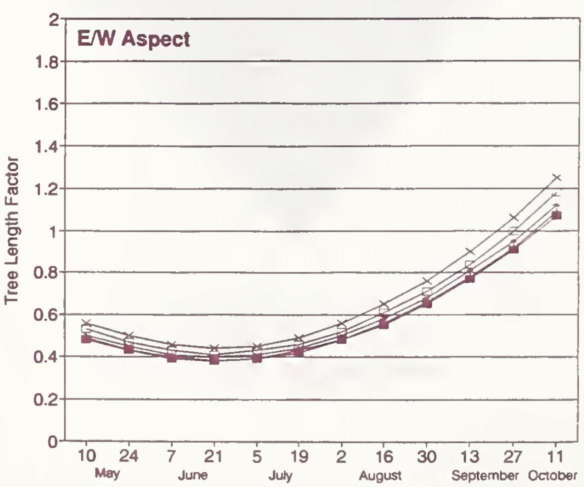


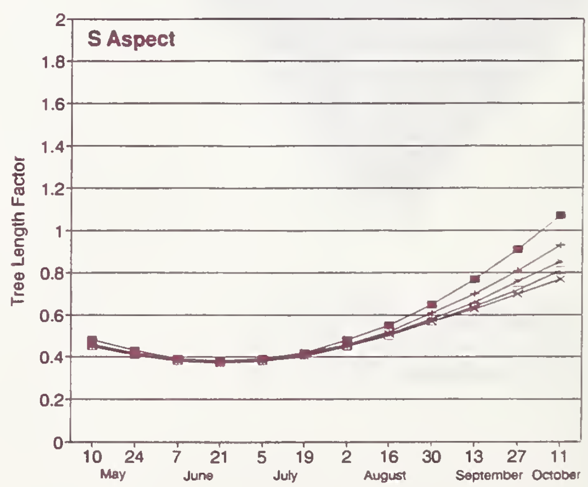
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.38		
N	15%	0.40	45%	0.47
	30%	0.43	60%	0.52
NE/NW	15%	0.39	45%	0.45
	30%	0.42	60%	0.50
E/W	15%	0.38	45%	0.41
	30%	0.40	60%	0.44
SE/SW	15%	0.37	45%	0.38
	30%	0.38	60%	0.40
S	15%	0.37	45%	0.37
	30%	0.37	60%	0.38







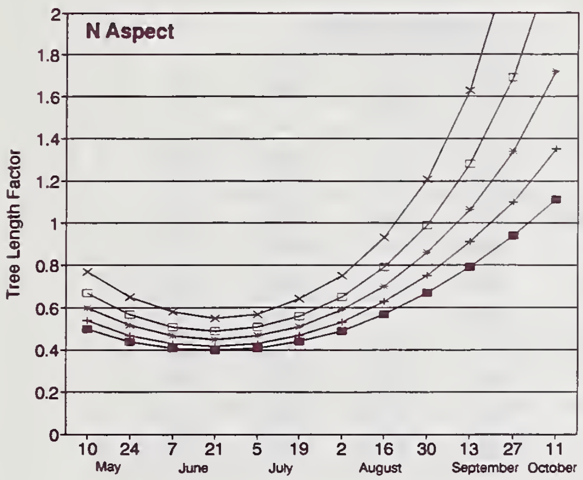


Flat Ground — 15% Slope — 30% Slope
45% Slope — 60% Slope

Latitude 39°

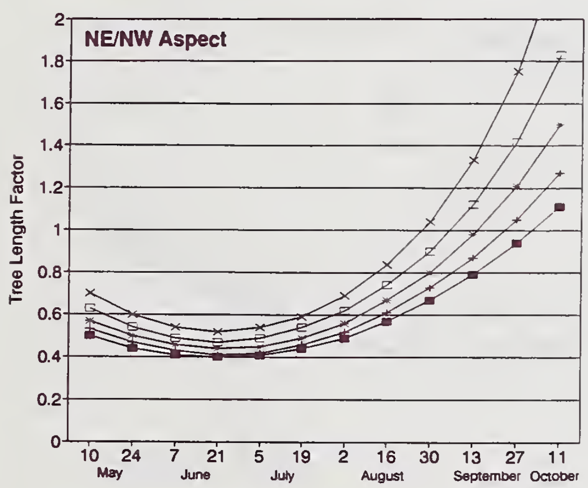
Reference area: 3 miles north of Fillmore, at Green River, UT

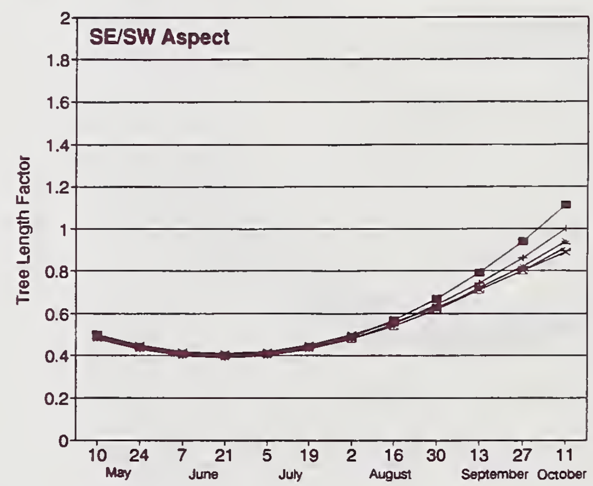
Tree length factors for cylinder-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

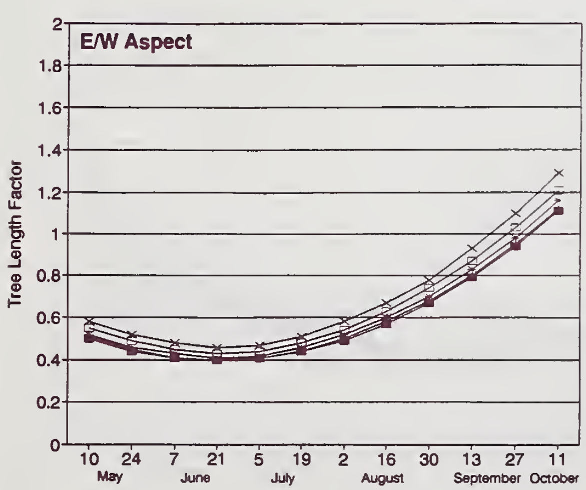


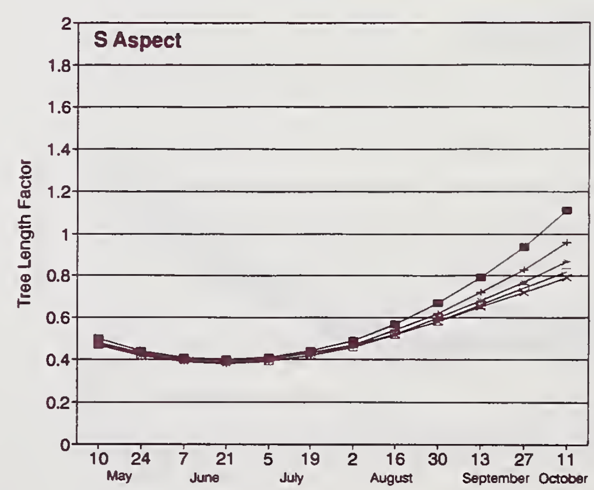
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.40		
N	15%	0.42	45%	0.49
	30%	0.45	60%	0.55
NE/NW	15%	0.41	45%	0.47
	30%	0.44	60%	0.52
E/W	15%	0.40	45%	0.43
	30%	0.41	60%	0.46
SE/SW	15%	0.39	45%	0.40
	30%	0.39	60%	0.41
S	15%	0.38	45%	0.39
	30%	0.38	60%	0.40







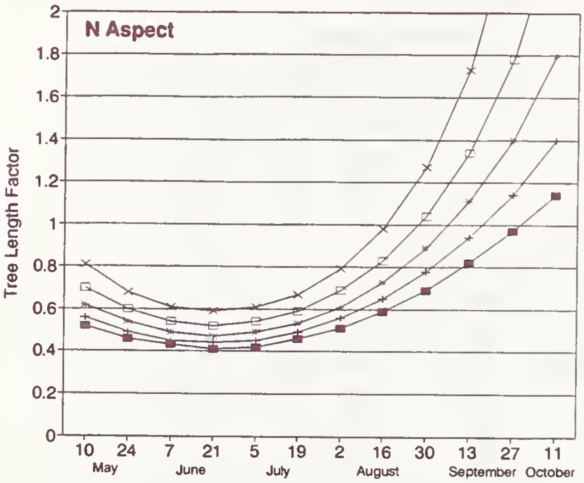


Flat Ground — 15% Slope — 30% Slope
45% Slope — 60% Slope

Latitude 40°

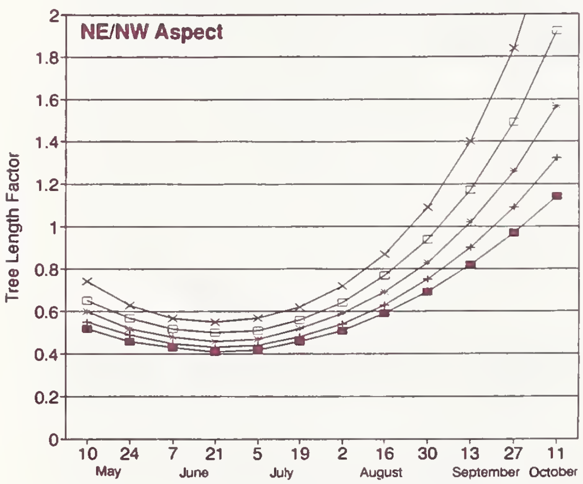
Reference area: 14 miles south of Provo, 30 miles south of Vernal, UT

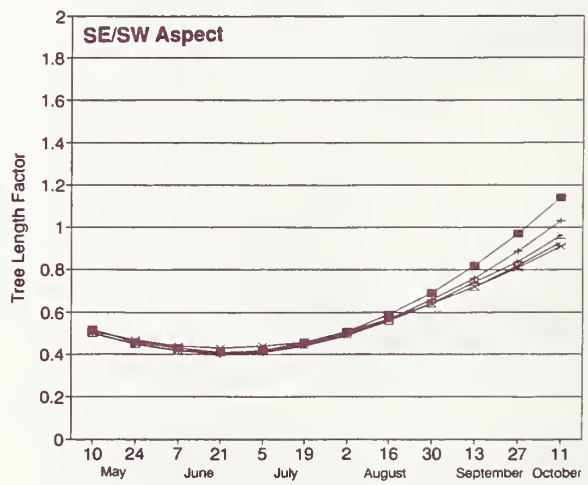
Tree length factors for cylinder-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

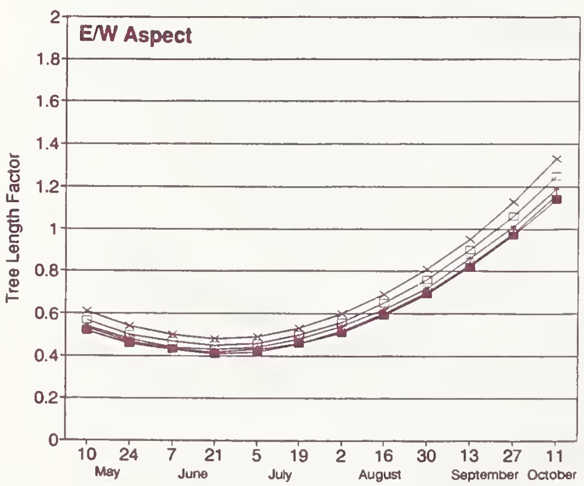


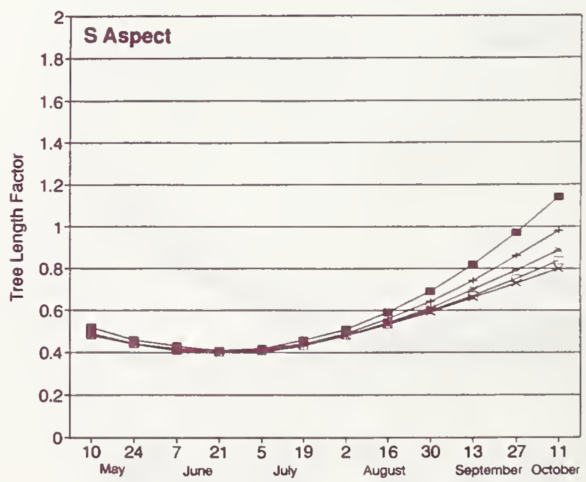
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.41		
N	15%	0.44	45%	0.52
	30%	0.47	60%	0.59
NE/NW	15%	0.43	45%	0.50
	30%	0.46	60%	0.55
E/W	15%	0.42	45%	0.45
	30%	0.43	60%	0.48
SE/SW	15%	0.40	45%	0.41
	30%	0.41	60%	0.43
S	15%	0.40	45%	0.40
	30%	0.40	60%	0.41







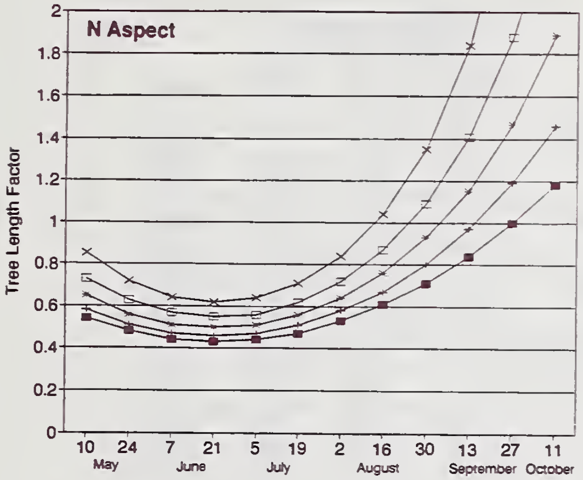


Flat Ground — 15% Slope — 30% Slope
45% Slope — 60% Slope

Latitude 41°

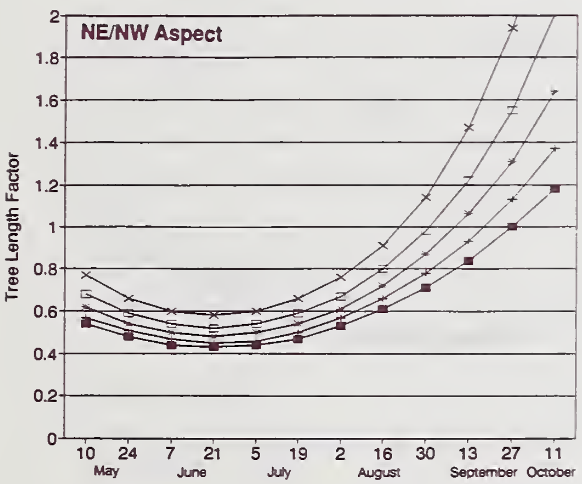
Reference area: 13 miles north of Salt Lake City, 16 miles south of Ogden, UT

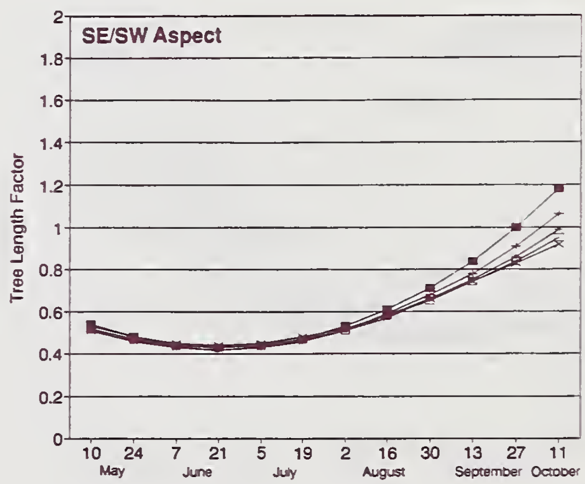
Tree length factors for cylinder-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

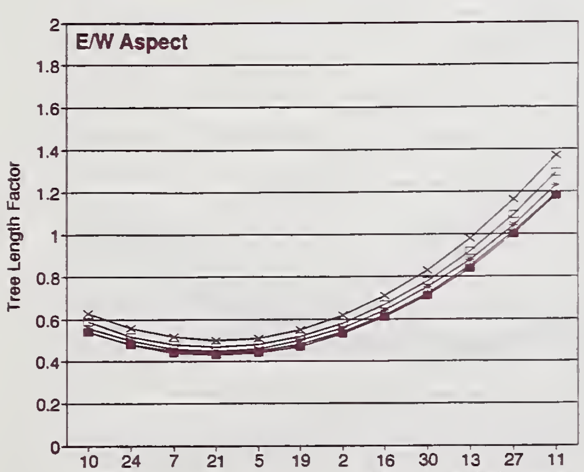


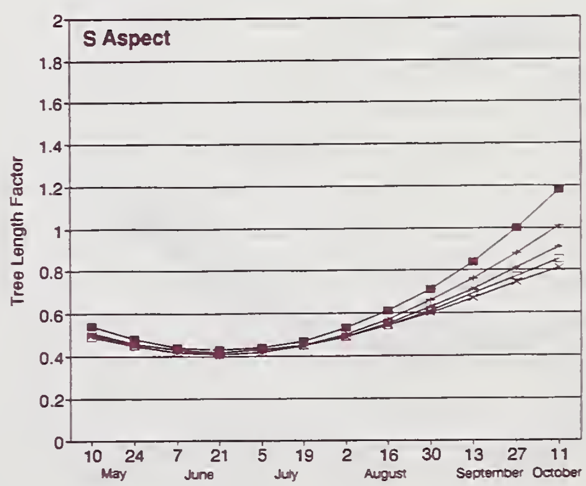
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.43		
N	15%	0.46	45%	0.55
	30%	0.50	60%	0.62
NE/NW	15%	0.45	45%	0.52
	30%	0.48	60%	0.58
E/W	15%	0.44	45%	0.47
	30%	0.45	60%	0.50
SE/SW	15%	0.42	45%	0.43
	30%	0.42	60%	0.44
S	15%	0.41	45%	0.41
	30%	0.41	60%	0.42







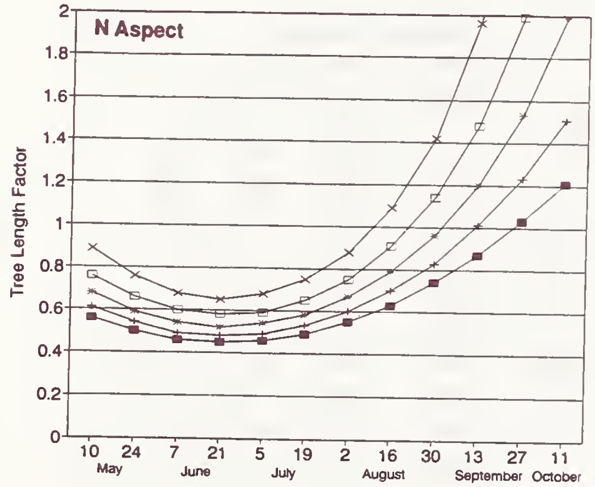


Flat Ground — 15% Slope — 30% Slope — 45% Slope — 60% Slope

Latitude 42°

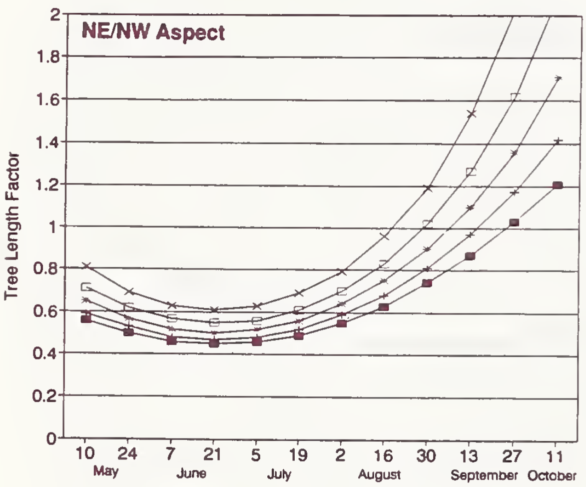
Reference area: Border between Utah and Idaho

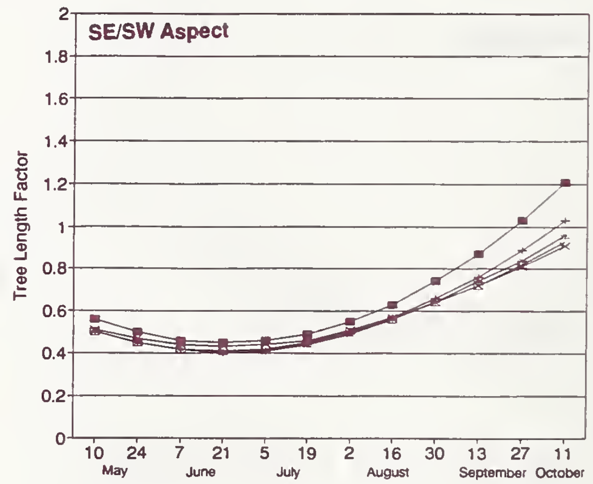
Tree length factors for cylinder-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

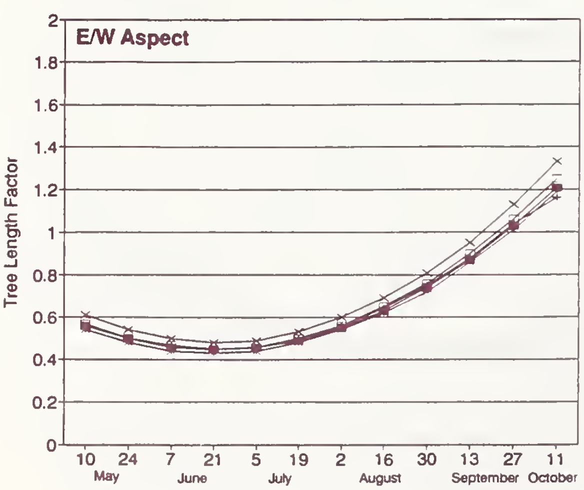


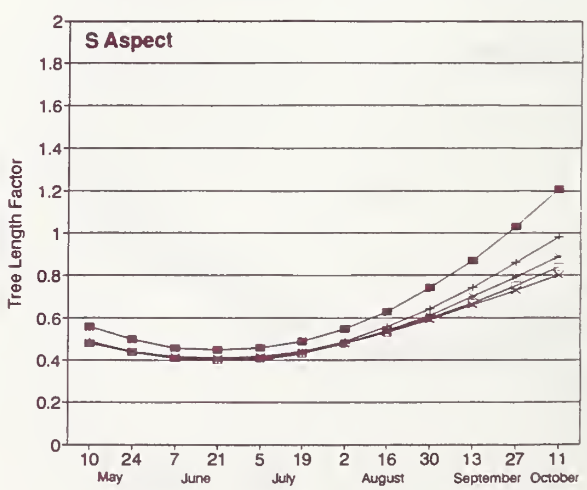
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.45		
N	15%	0.48	45%	0.58
	30%	0.52	60%	0.65
NE/NW	15%	0.47	45%	0.55
	30%	0.50	60%	0.61
E/W	15%	0.45	45%	0.49
	30%	0.47	60%	0.52
SE/SW	15%	0.44	45%	0.44
	30%	0.44	60%	0.46
S	15%	0.43	45%	0.43
	30%	0.42	60%	0.43







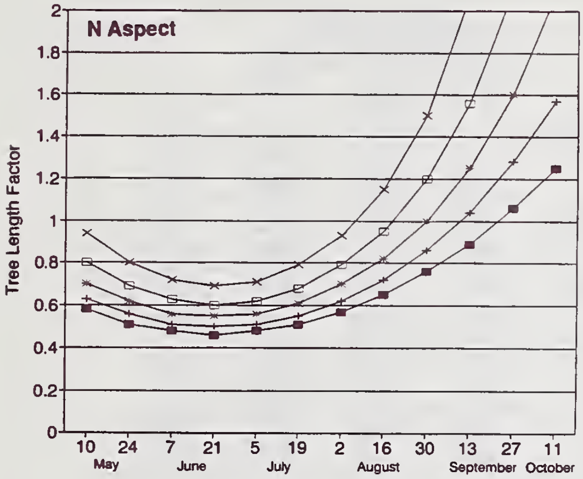


Flat Ground — 15% Slope — 30% Slope
45% Slope — 60% Slope

Latitude 43°

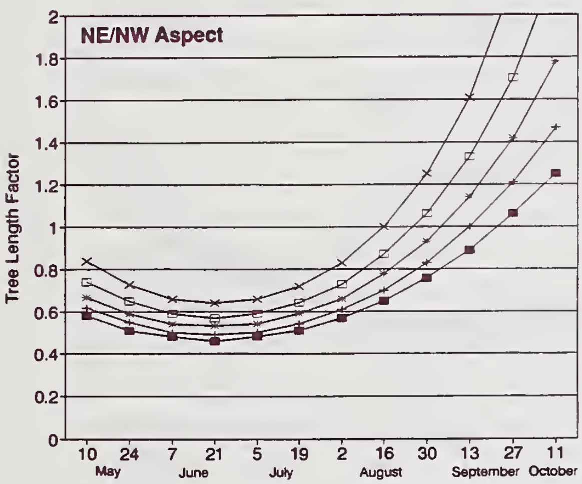
Reference area: at Glenns Ferry, 12 miles north of Pocatello, ID

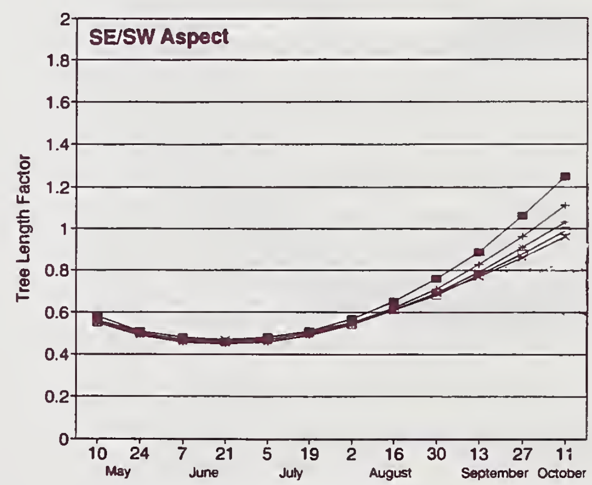
Tree length factors for cylinder-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

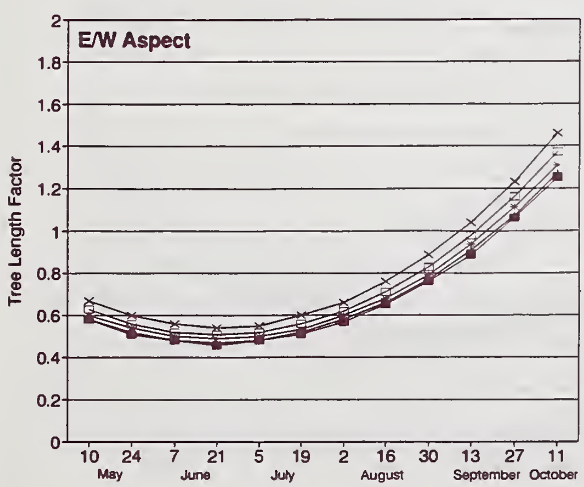


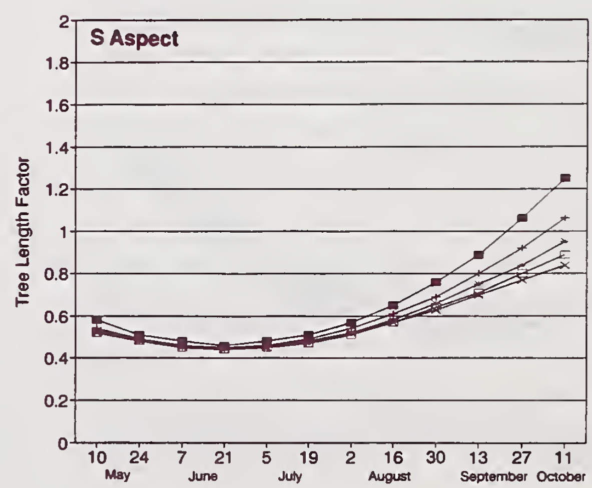
Shortest shadow
June 21 at solar noon

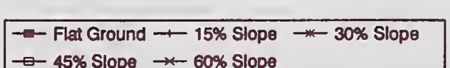
	Slope	Len.	Slope	Len.
Flat		0.46		
N	15%	0.50	45%	0.60
	30%	0.55	60%	0.69
NE/NW	15%	0.49	45%	0.57
	30%	0.53	60%	0.64
E/W	15%	0.47	45%	0.51
	30%	0.49	60%	0.54
SE/SW	15%	0.45	45%	0.46
	30%	0.45	60%	0.47
S	15%	0.45	45%	0.44
	30%	0.44	60%	0.45







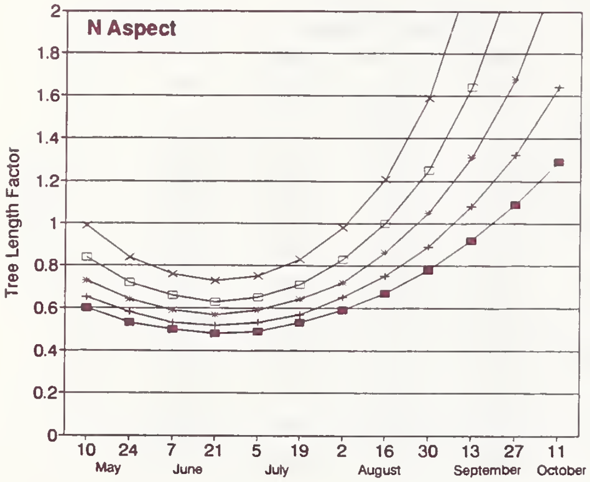




Latitude 44°

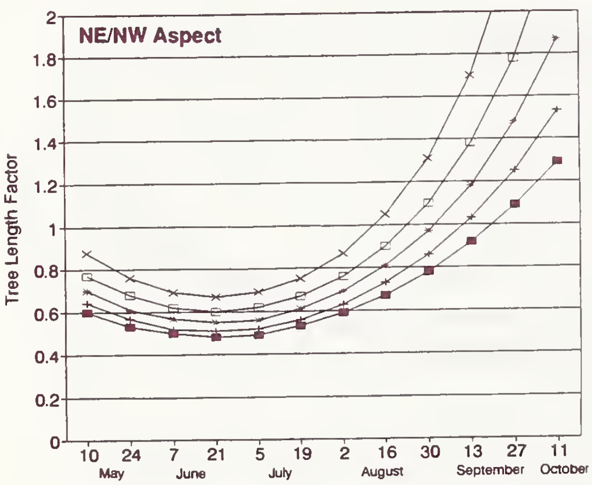
Reference area: 5 miles north of Horseshoe Bend, 2 miles north of St. Anthony, ID

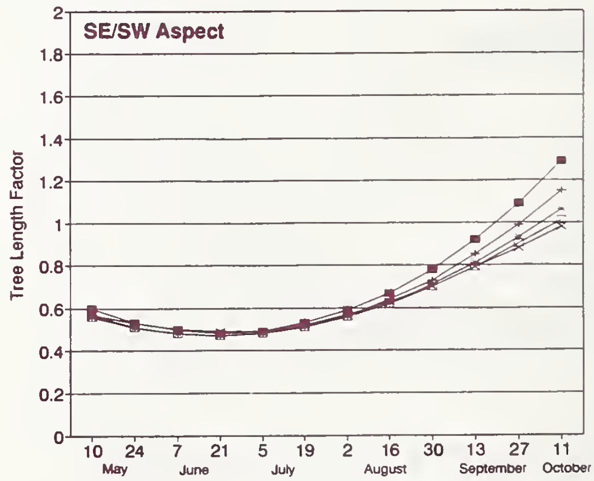
Tree length factors for cylinder-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

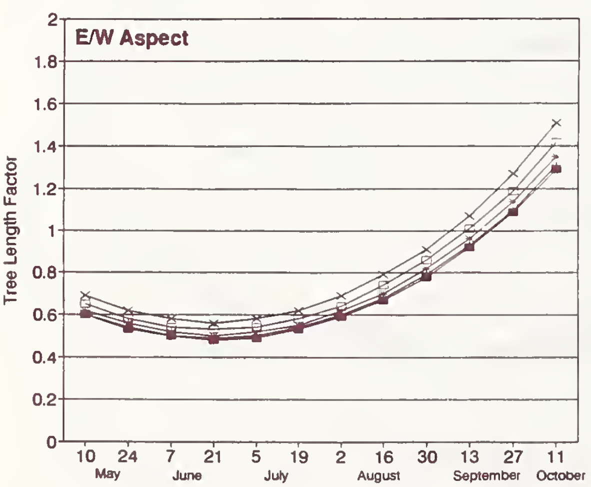


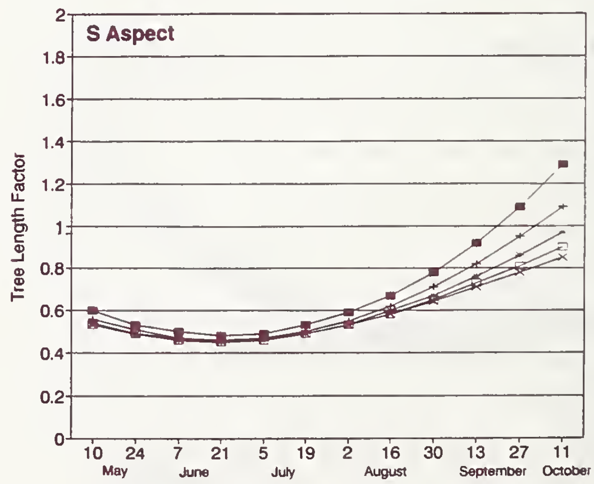
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.48		
N	15%	0.52	45%	0.63
	30%	0.57	60%	0.73
NE/NW	15%	0.51	45%	0.60
	30%	0.55	60%	0.67
E/W	15%	0.49	45%	0.53
	30%	0.50	60%	0.56
SE/SW	15%	0.47	45%	0.47
	30%	0.47	60%	0.49
S	15%	0.46	45%	0.45
	30%	0.45	60%	0.46





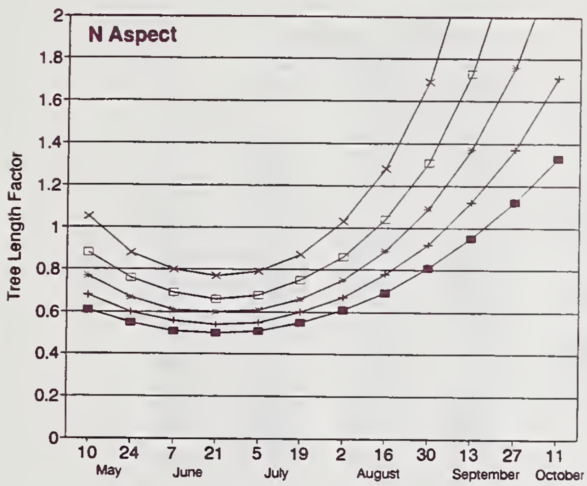




Latitude 45°

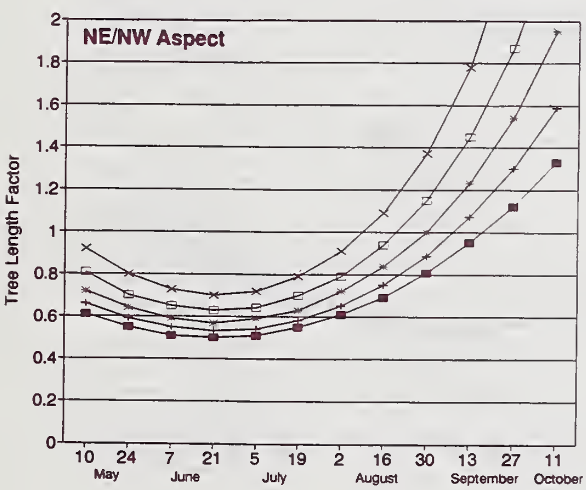
Reference area: 1.5 miles north of New Meadows, 9 miles south of Salmon, ID

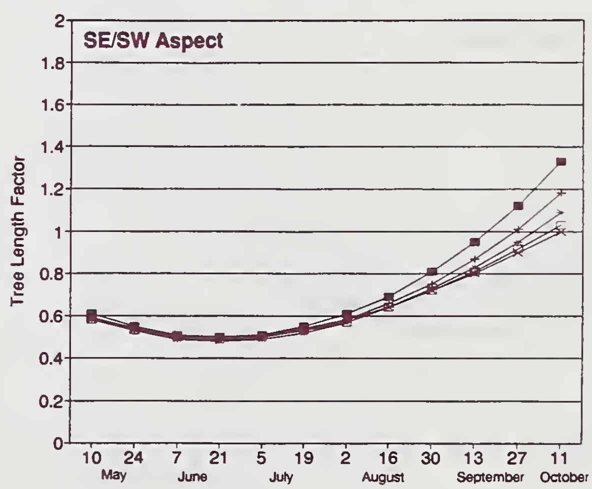
Tree length factors for cylinder-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

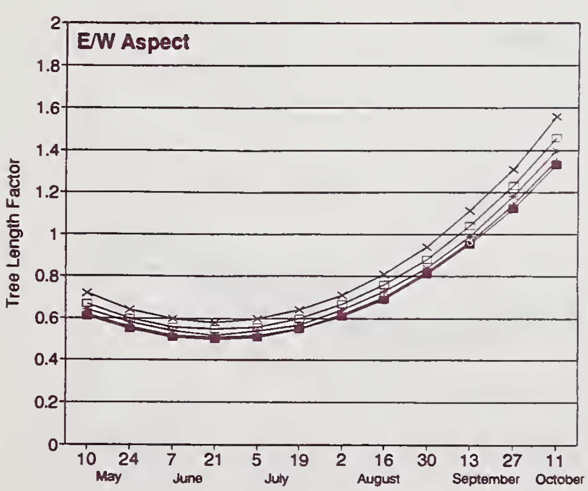


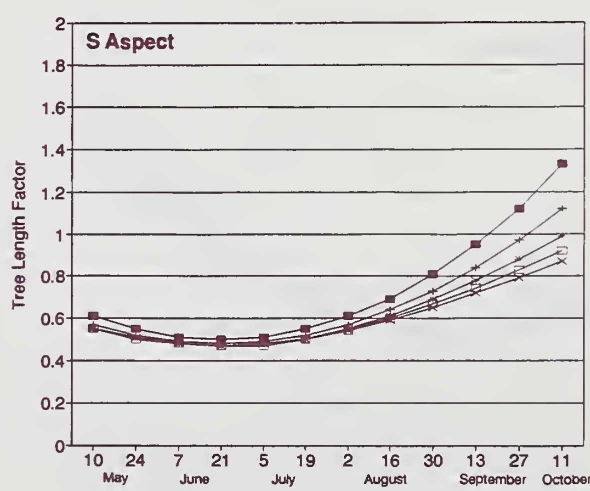
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.50		
N	15%	0.54	45%	0.66
	30%	0.60	60%	0.77
NE/NW	15%	0.53	45%	0.63
	30%	0.57	60%	0.70
E/W	15%	0.51	45%	0.55
	30%	0.52	60%	0.58
SE/SW	15%	0.49	45%	0.49
	30%	0.48	60%	0.50
S	15%	0.48	45%	0.47
	30%	0.47	60%	0.47







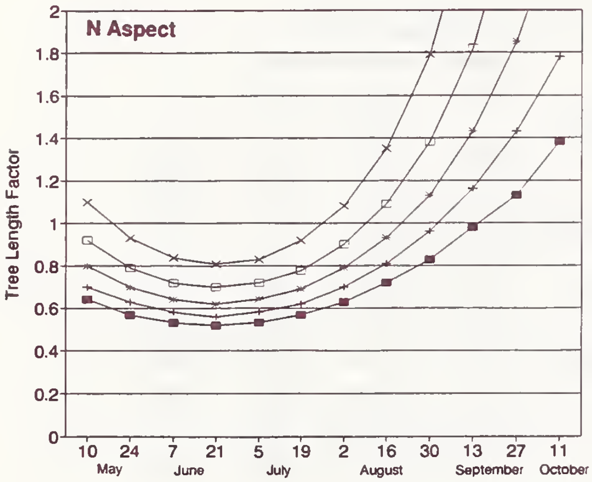


Flat Ground — 15% Slope — 30% Slope
45% Slope — 60% Slope

Latitude 46°

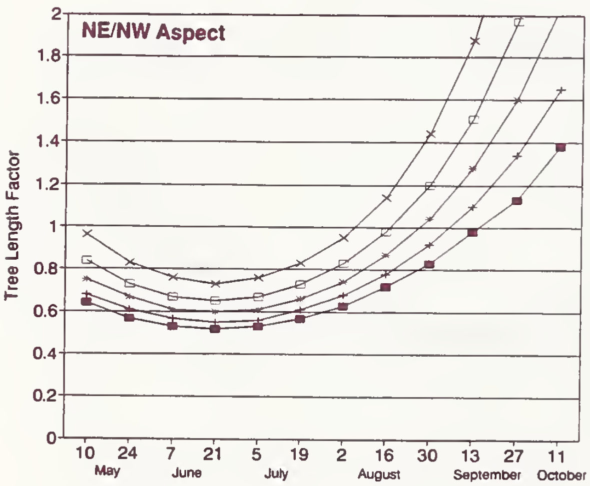
Reference area: 5 miles north of Grangeville, ID

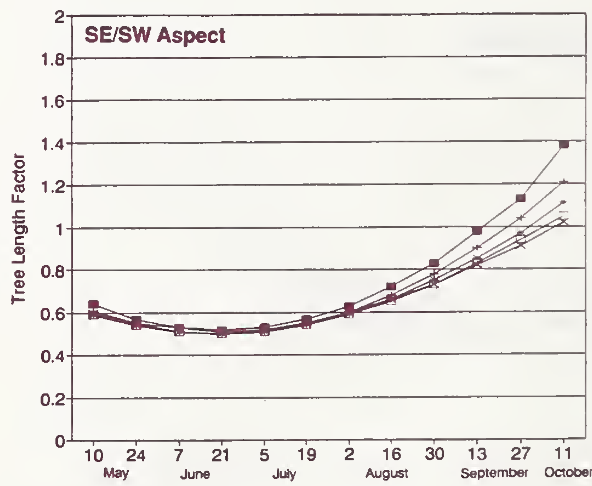
Tree length factors for cylinder-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

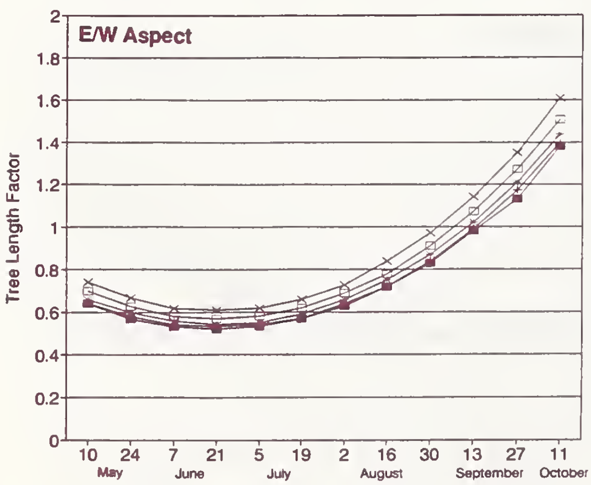


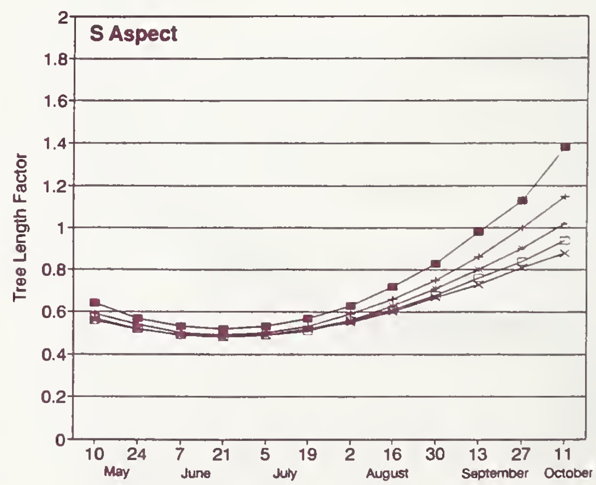
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.52		
N	15%	0.56	45%	0.70
	30%	0.62	60%	0.81
NE/NW	15%	0.55	45%	0.65
	30%	0.60	60%	0.73
E/W	15%	0.53	45%	0.57
	30%	0.54	60%	0.61
SE/SW	15%	0.50	45%	0.50
	30%	0.50	60%	0.51
S	15%	0.49	45%	0.48
	30%	0.48	60%	0.48







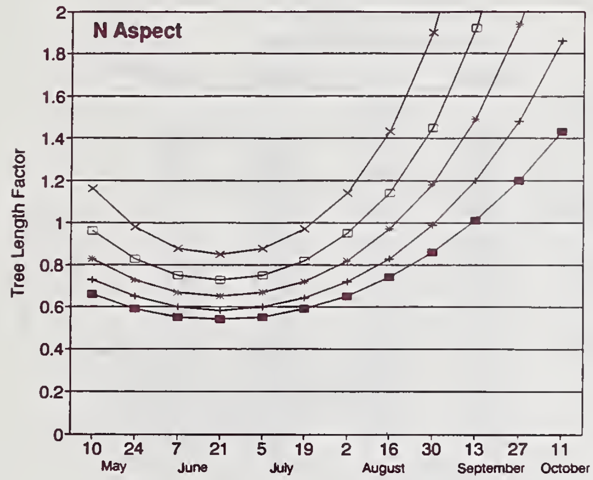


Flat Ground — 15% Slope — 30% Slope
45% Slope — 60% Slope

Latitude 47°

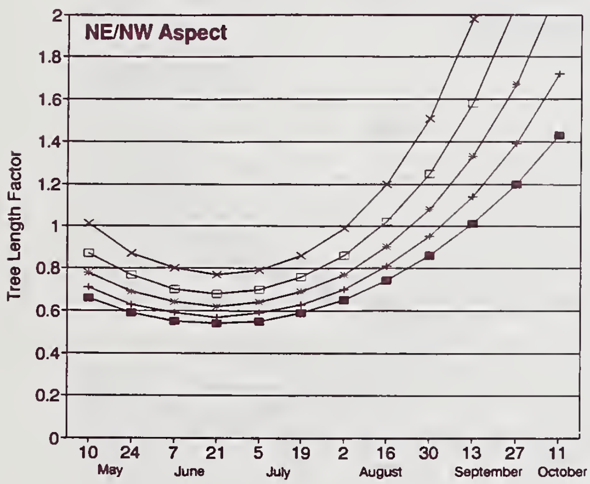
Reference area: 6 miles north of Boville, 2 miles south of Clarkia, ID

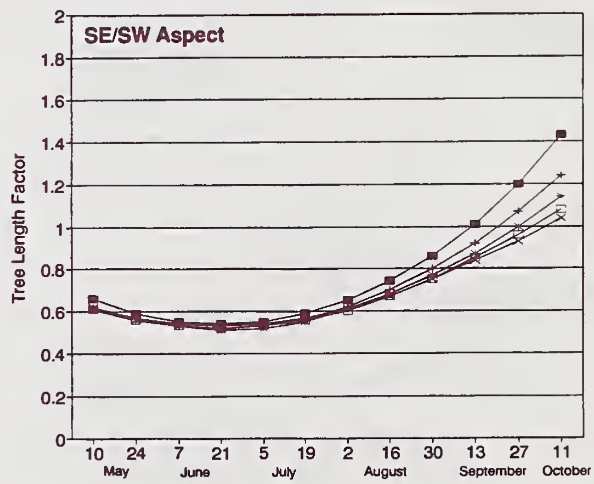
Tree length factors for cylinder-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

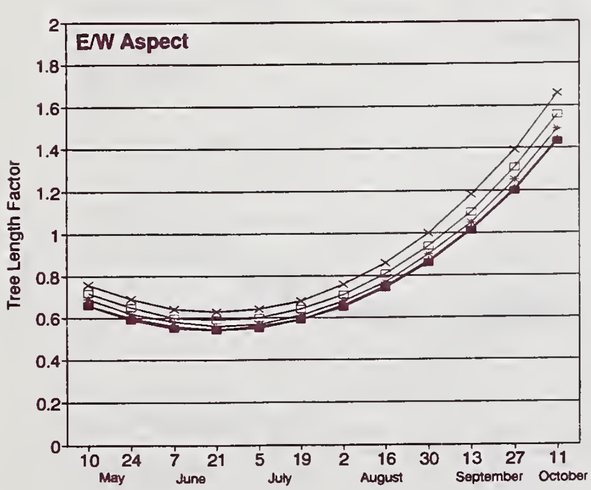


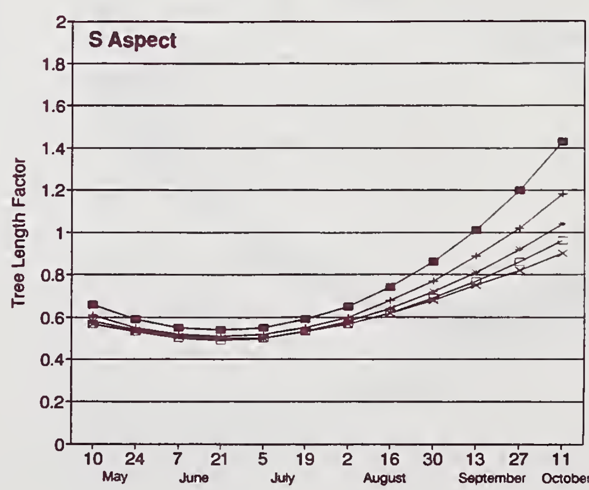
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.54		
N	15%	0.58	45%	0.73
	30%	0.65	60%	0.85
NE/NW	15%	0.57	45%	0.68
	30%	0.62	60%	0.77
E/W	15%	0.54	45%	0.59
	30%	0.56	60%	0.63
SE/SW	15%	0.52	45%	0.52
	30%	0.51	60%	0.53
S	15%	0.51	45%	0.49
	30%	0.50	60%	0.50







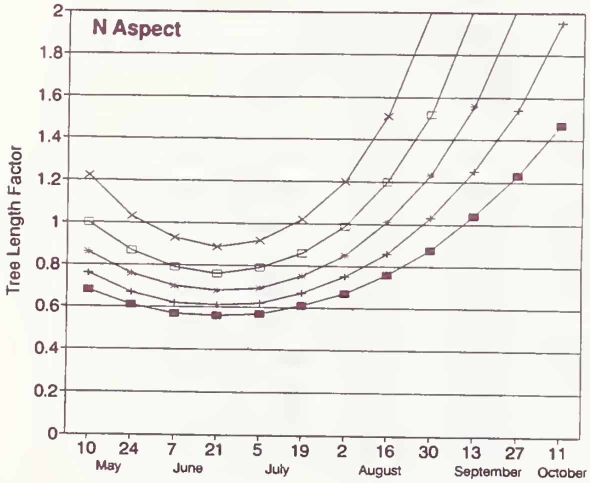


Flat Ground — 15% Slope — 30% Slope
45% Slope — 60% Slope

Latitude 48°

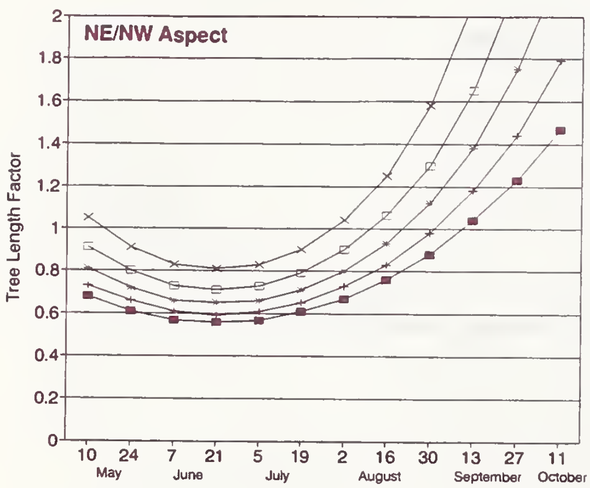
Reference area: 20 miles north of Coeur d'Alene, ID

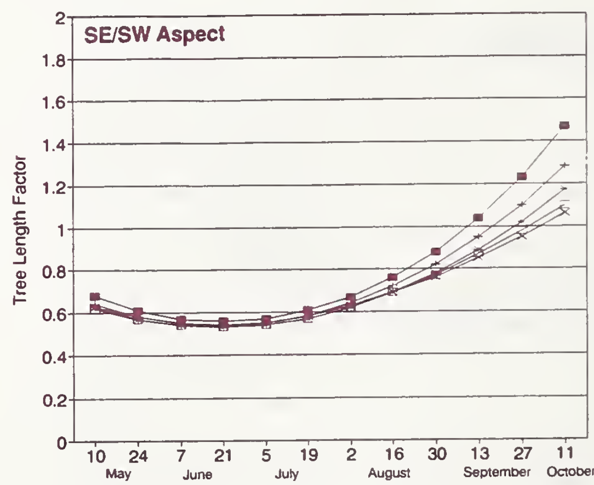
Tree length factors for cylinder-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

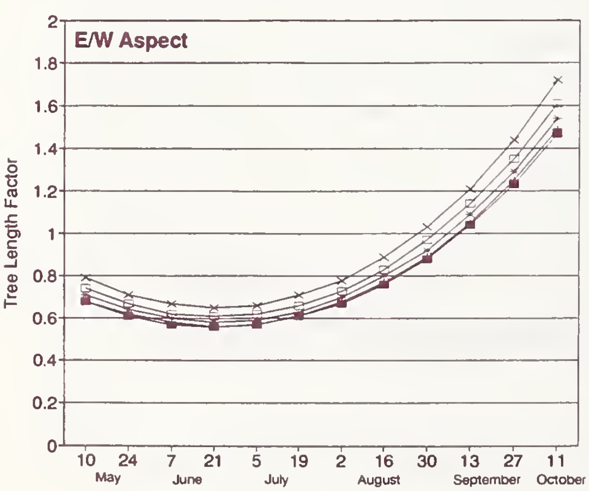


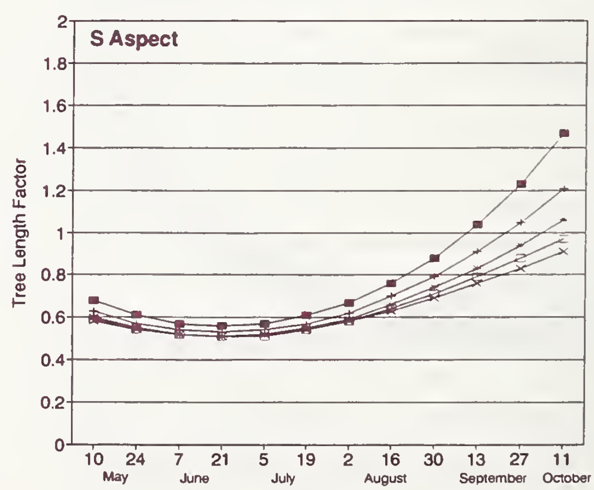
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.56		
N	15%	0.61	45%	0.76
	30%	0.68	60%	0.89
NE/NW	15%	0.59	45%	0.71
	30%	0.65	60%	0.81
E/W	15%	0.56	45%	0.61
	30%	0.58	60%	0.65
SE/SW	15%	0.54	45%	0.53
	30%	0.53	60%	0.54
S	15%	0.53	45%	0.51
	30%	0.51	60%	0.51









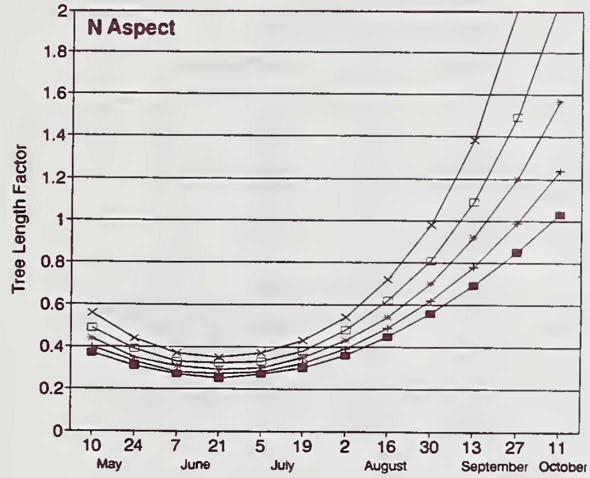
Flat Ground — 15% Slope — 30% Slope — 45% Slope — 60% Slope

Appendix F

Latitude 38°

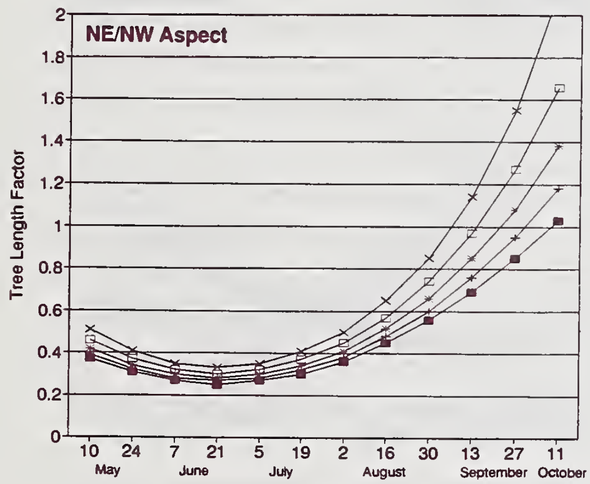
Reference area: 13 miles north of Panguitch, 9 miles north of Monticello, UT

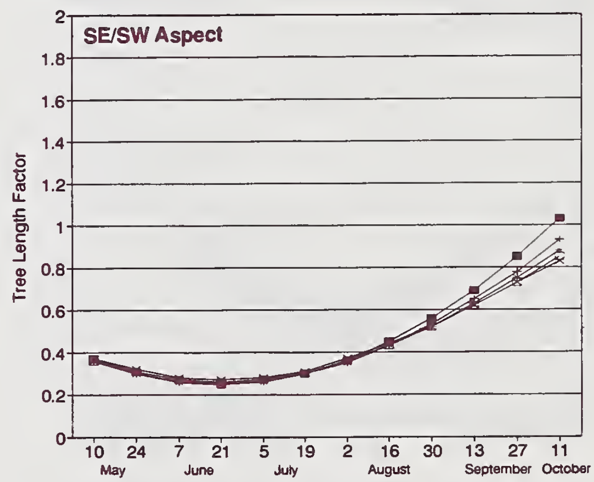
Tree length factors for cone-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

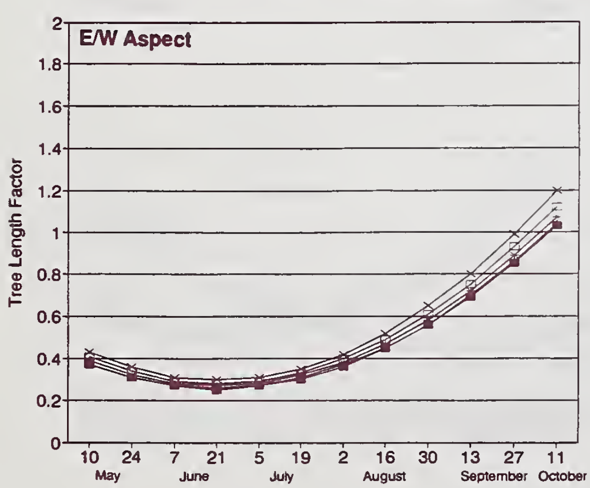


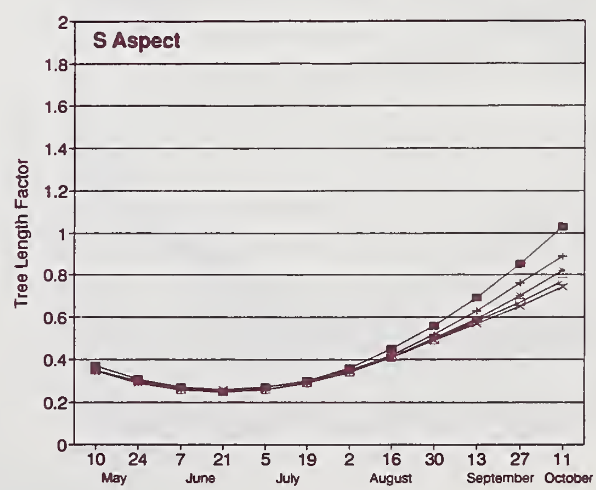
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.25		
N	15%	0.27	45%	0.32
	30%	0.29	60%	0.35
NE/NW	15%	0.27	45%	0.30
	30%	0.28	60%	0.33
E/W	15%	0.26	45%	0.28
	30%	0.27	60%	0.30
SE/SW	15%	0.25	45%	0.26
	30%	0.25	60%	0.27
S	15%	0.25	45%	0.25
	30%	0.25	60%	0.26





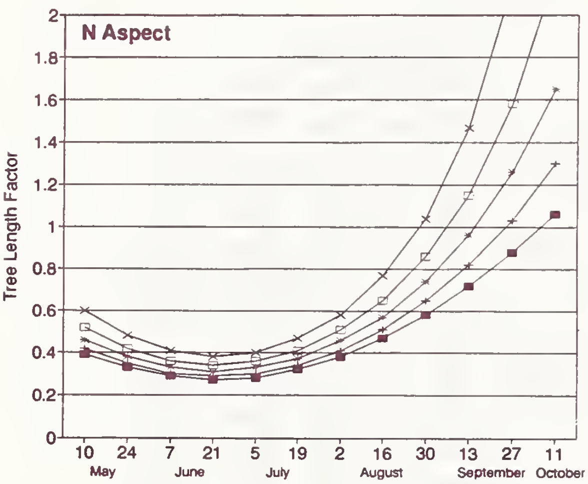




Latitude 39°

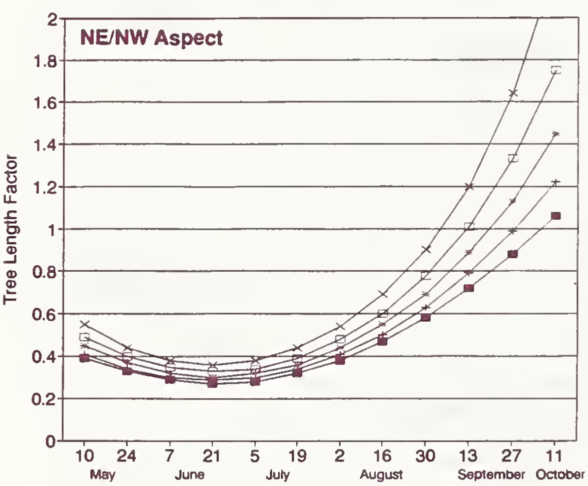
Reference area: 3 miles north of Fillmore, at Green River, UT

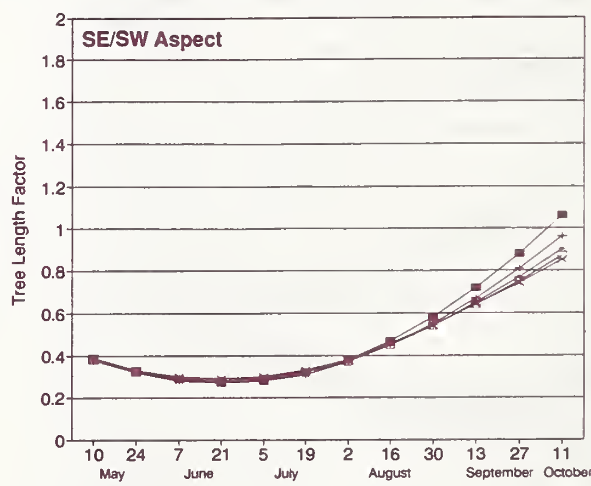
Tree length factors for cone-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

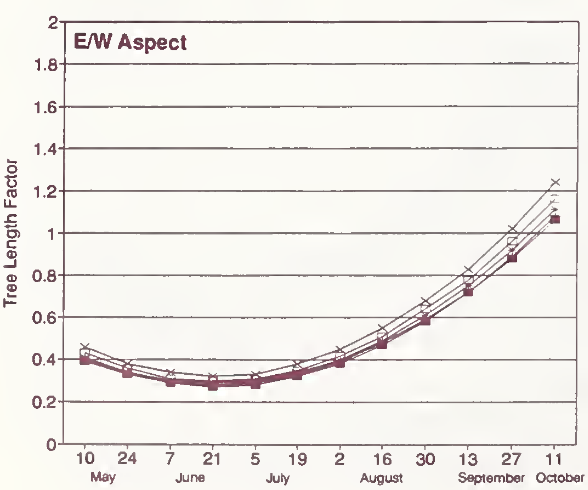


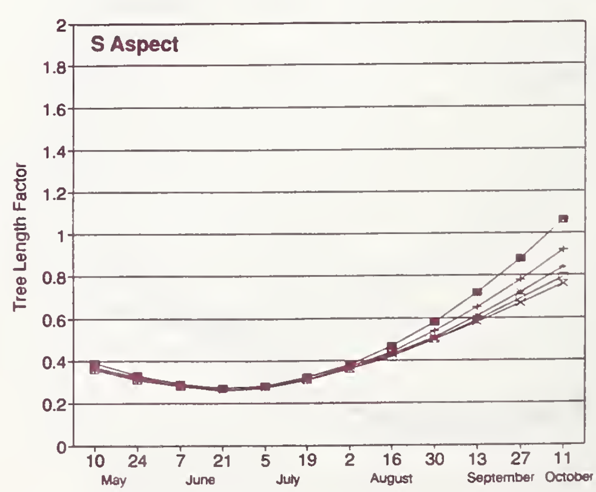
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.27		
N	15%	0.29	45%	0.34
	30%	0.31	60%	0.38
NE/NW	15%	0.29	45%	0.33
	30%	0.30	60%	0.36
E/W	15%	0.28	45%	0.30
	30%	0.29	60%	0.32
SE/SW	15%	0.27	45%	0.28
	30%	0.27	60%	0.29
S	15%	0.27	45%	0.27
	30%	0.26	60%	0.27







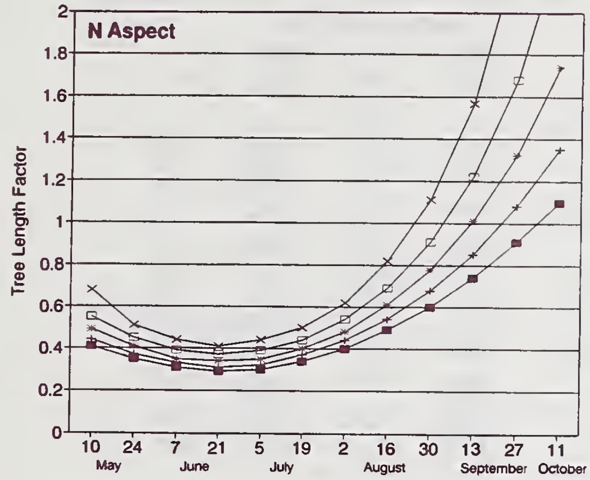


Flat Ground — 15% Slope — 30% Slope
45% Slope — 60% Slope

Latitude 40°

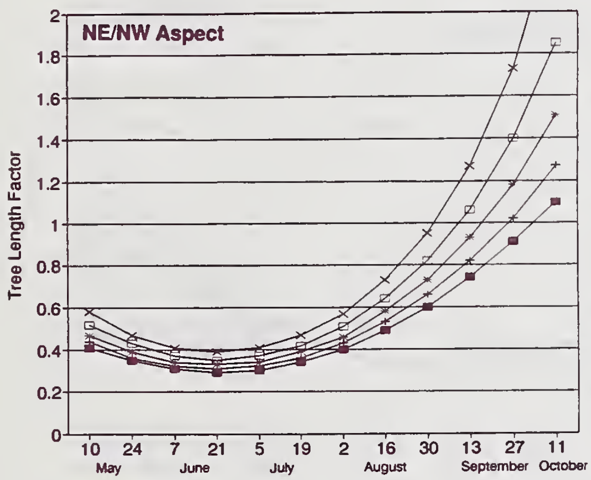
Reference area: 14 miles south of Provo, 30 miles south of Vernal, UT

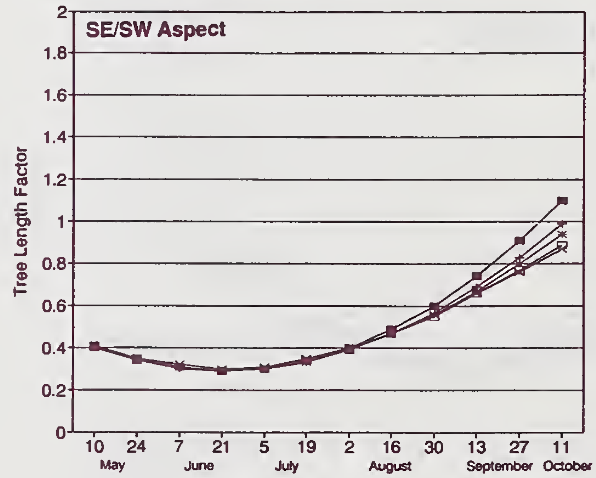
Tree length factors for cone-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

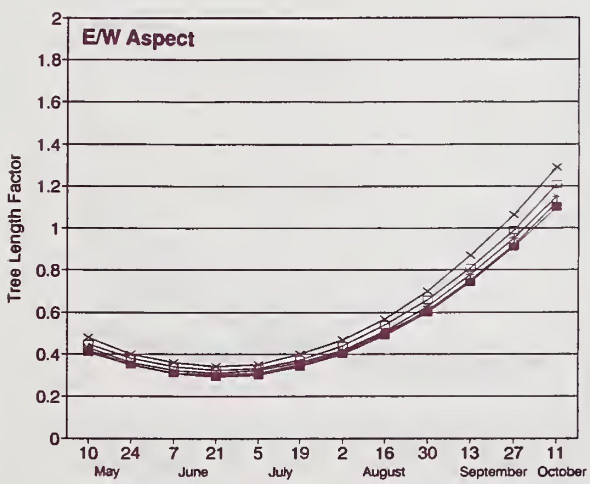


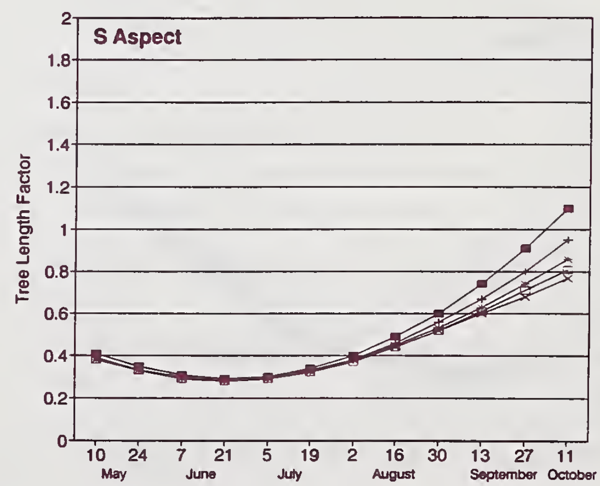
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.29		
N	15%	0.31	45%	0.37
	30%	0.34	60%	0.41
NE/NW	15%	0.31	45%	0.35
	30%	0.33	60%	0.39
E/W	15%	0.30	45%	0.32
	30%	0.31	60%	0.34
SE/SW	15%	0.29	45%	0.29
	30%	0.30	60%	0.30
S	15%	0.28	45%	0.28
	30%	0.28	60%	0.29







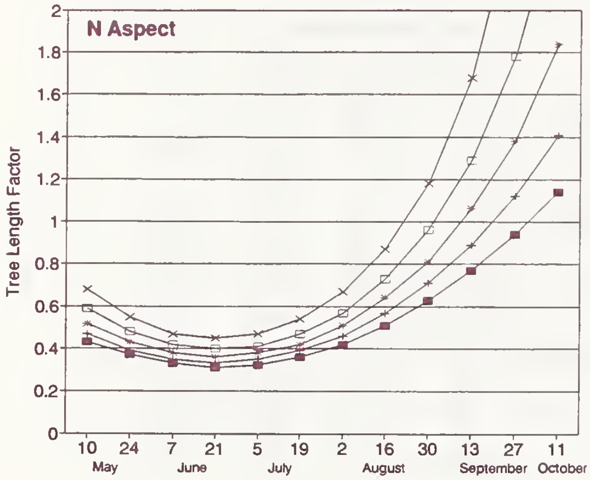


Flat Ground — 15% Slope — 30% Slope — 45% Slope — 60% Slope

Latitude 41°

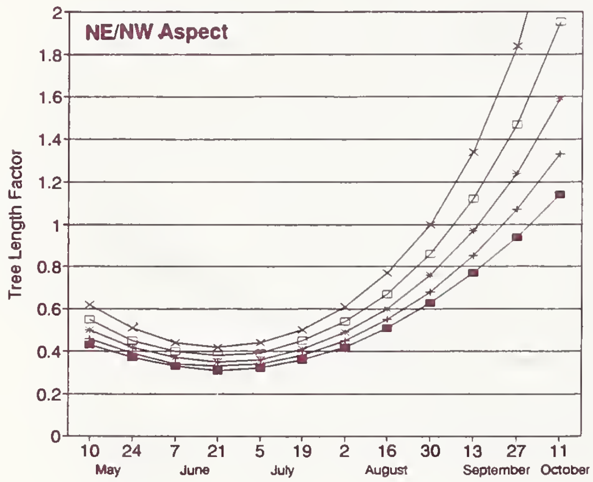
Reference area: 13 miles north of Salt Lake City, 16 miles south of Ogden, UT

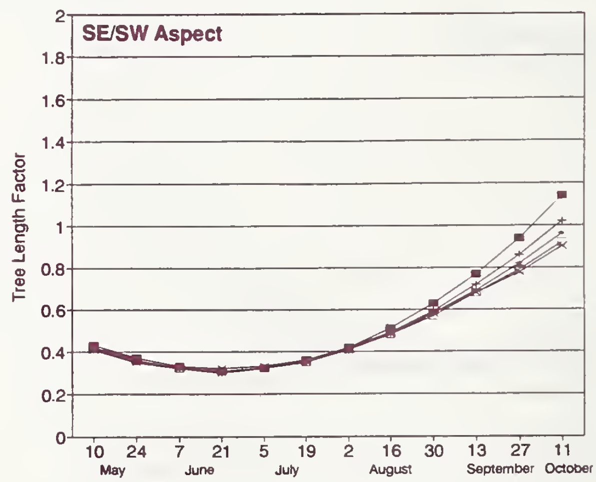
Tree length factors for cone-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

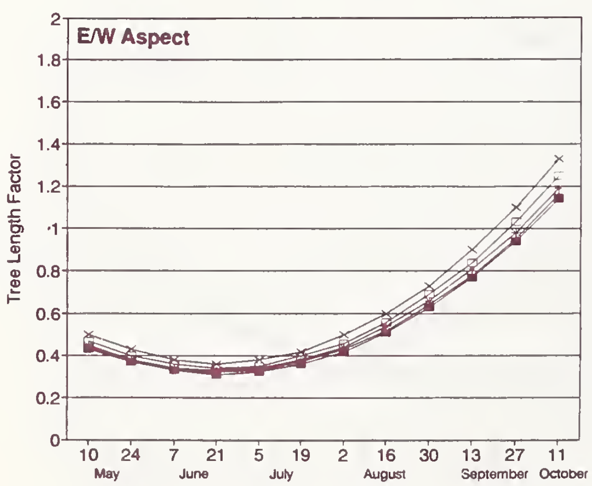


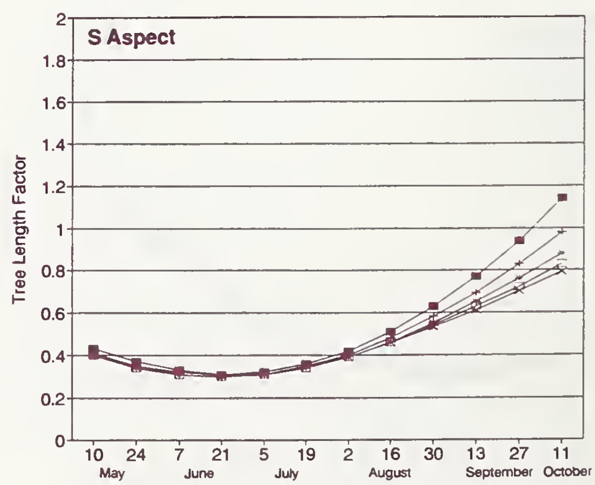
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.31		
N	15%	0.33	45%	0.40
	30%	0.36	60%	0.45
NE/NW	15%	0.33	45%	0.38
	30%	0.35	60%	0.42
E/W	15%	0.32	45%	0.34
	30%	0.33	60%	0.36
SE/SW	15%	0.30	45%	0.31
	30%	0.30	60%	0.32
S	15%	0.30	45%	0.30
	30%	0.30	60%	0.31





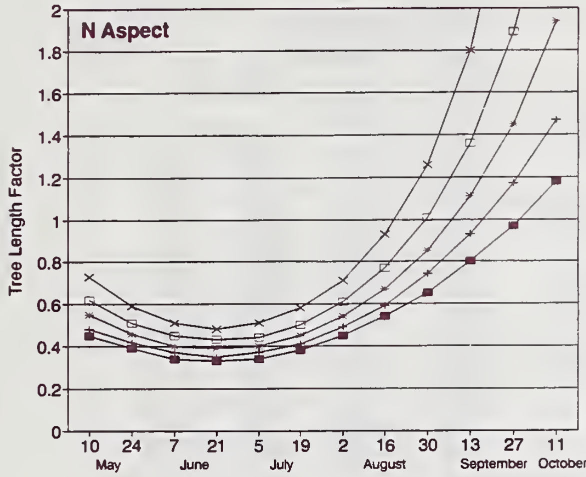




Latitude 42°

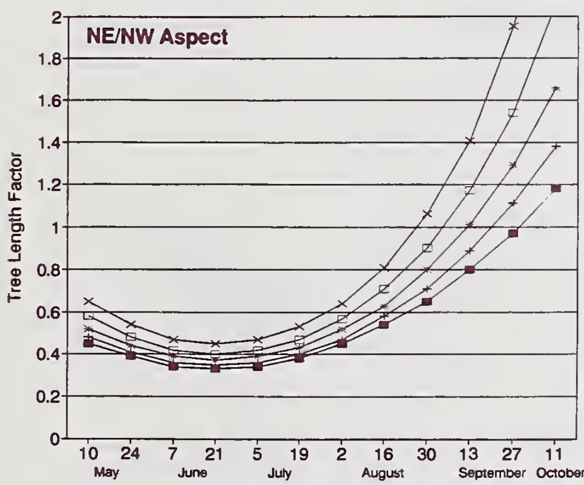
Reference area: Border between Utah and Idaho

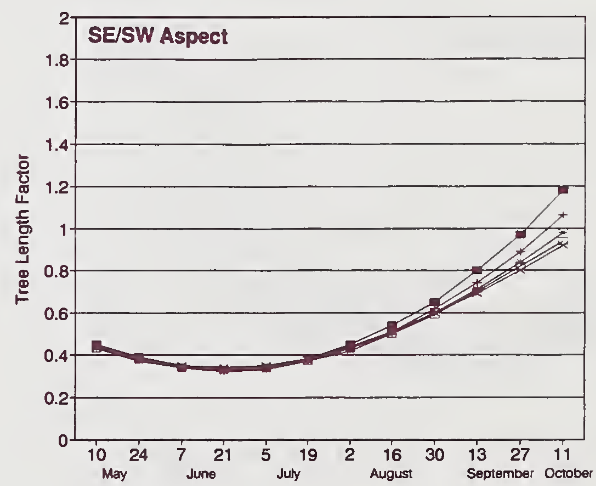
Tree length factors for cone-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

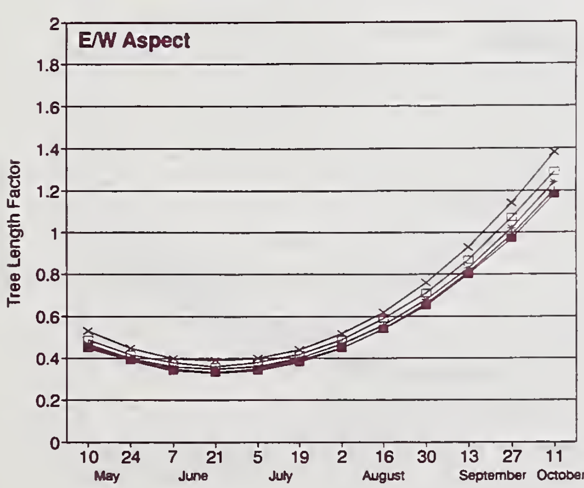


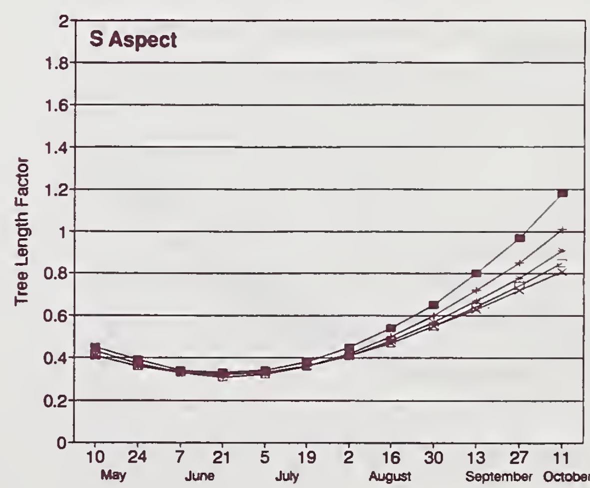
Shortest shadow June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.33		
N	15%	0.35	45%	0.43
	30%	0.39	60%	0.48
NE/NW	15%	0.35	45%	0.40
	30%	0.37	60%	0.45
E/W	15%	0.33	45%	0.36
	30%	0.35	60%	0.39
SE/SW	15%	0.32	45%	0.33
	30%	0.32	60%	0.34
S	15%	0.32	45%	0.31
	30%	0.31	60%	0.32







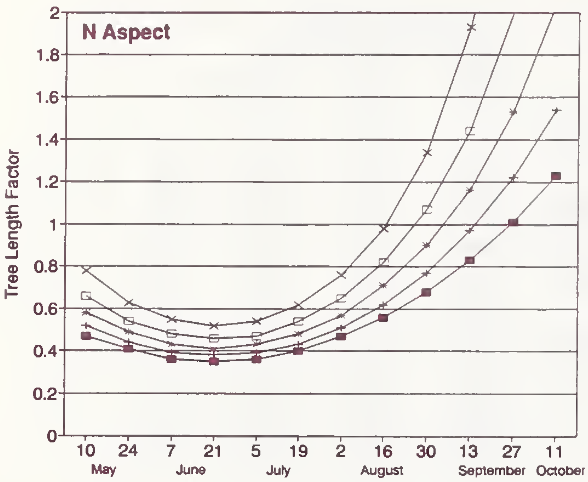


Flat Ground — 15% Slope — 30% Slope
45% Slope — 60% Slope

Latitude 43°

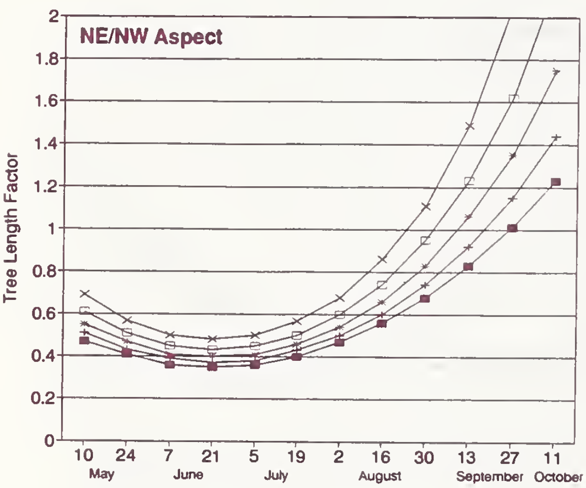
Reference area: at Glenns Ferry, 12 miles north of Pocatello, ID

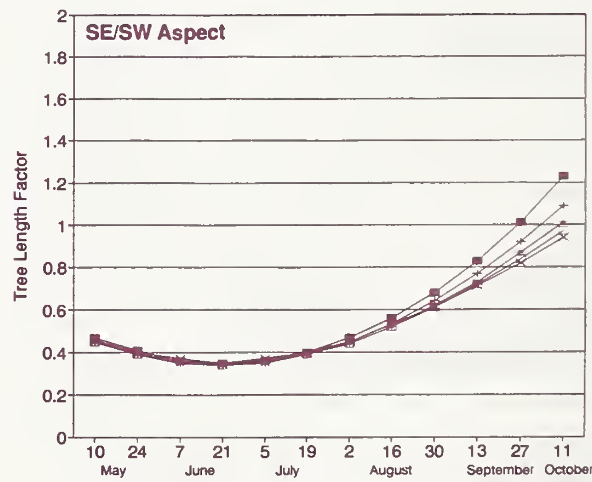
Tree length factors for cone-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

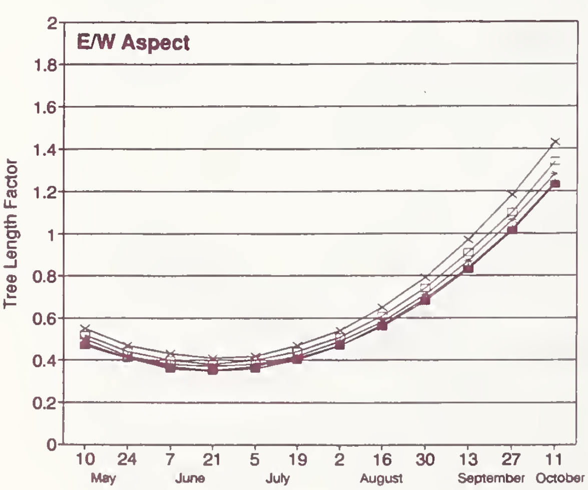


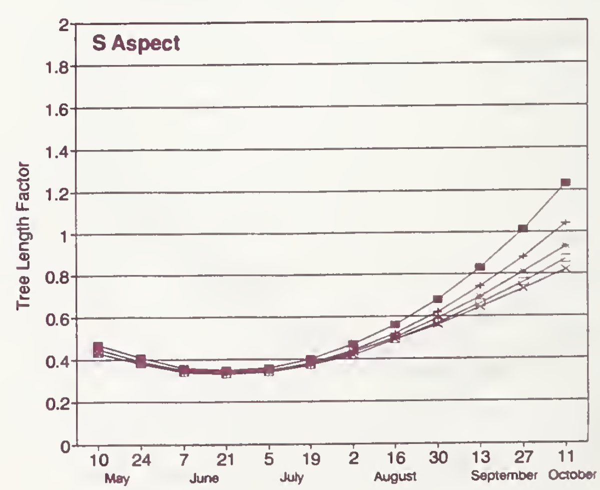
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.35		
N	15%	0.38	45%	0.46
	30%	0.41	60%	0.52
NE/NW	15%	0.37	45%	0.43
	30%	0.40	60%	0.48
E/W	15%	0.35	45%	0.38
	30%	0.37	60%	0.41
SE/SW	15%	0.34	45%	0.34
	30%	0.34	60%	0.35
S	15%	0.34	45%	0.33
	30%	0.34	60%	0.34







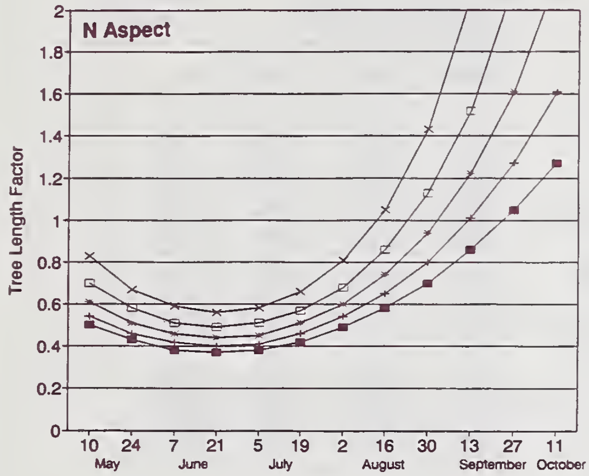


Flat Ground — 15% Slope — 30% Slope
45% Slope — 60% Slope

Latitude 44°

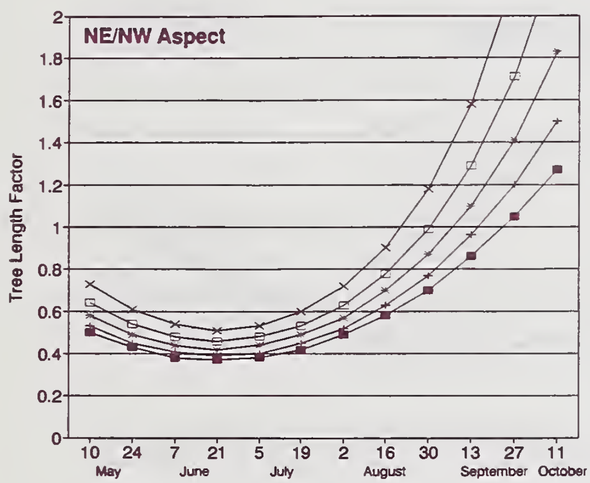
Reference area: 5 miles north Horseshoe Bend, 2 miles north of St. Anthony, ID

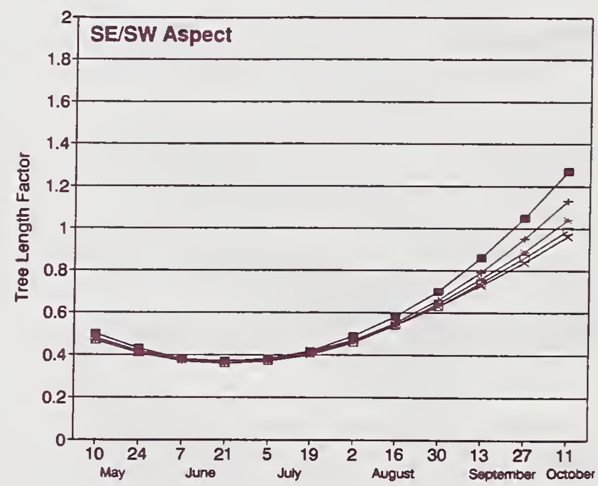
Tree length factors for cone-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

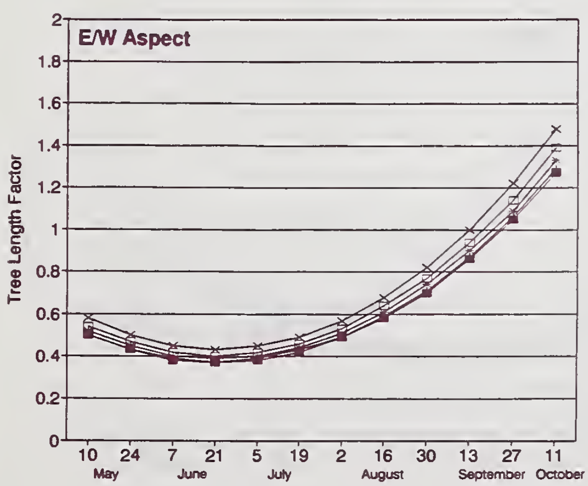


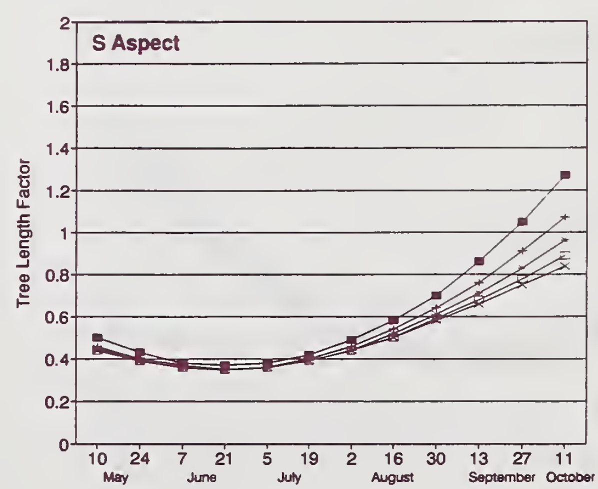
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.37		
N	15%	0.40	45%	0.49
	30%	0.44	60%	0.56
NE/NW	15%	0.39	45%	0.46
	30%	0.42	60%	0.51
E/W	15%	0.37	45%	0.40
	30%	0.39	60%	0.43
SE/SW	15%	0.36	45%	0.36
	30%	0.36	60%	0.37
S	15%	0.35	45%	0.35
	30%	0.35	60%	0.35







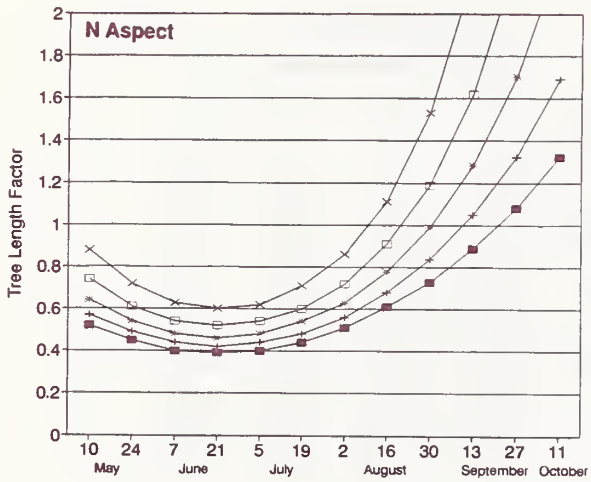


Flat Ground — 15% Slope — 30% Slope — 45% Slope — 60% Slope

Latitude 45°

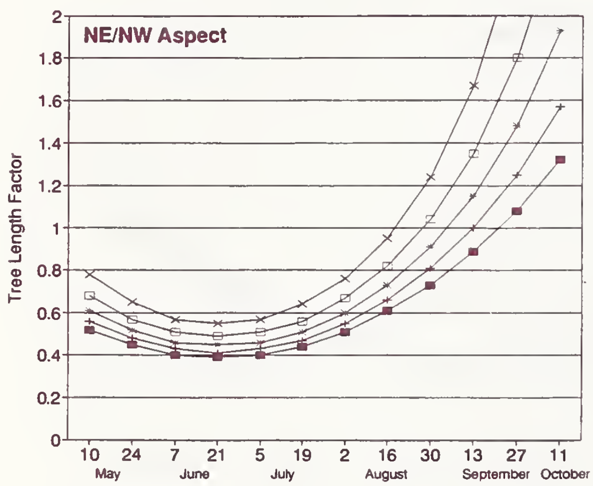
Reference area: 1.5 miles north of New Meadows, 9 miles south of Salmon, ID

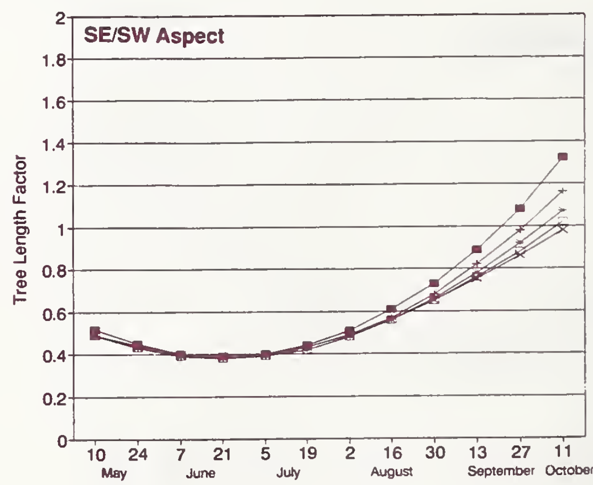
Tree length factors for cone-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

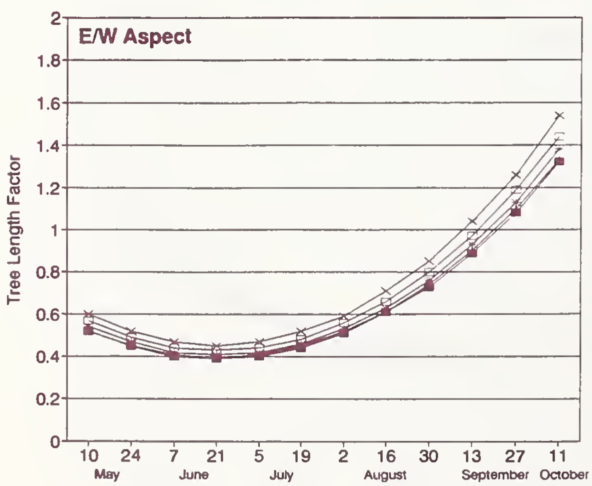


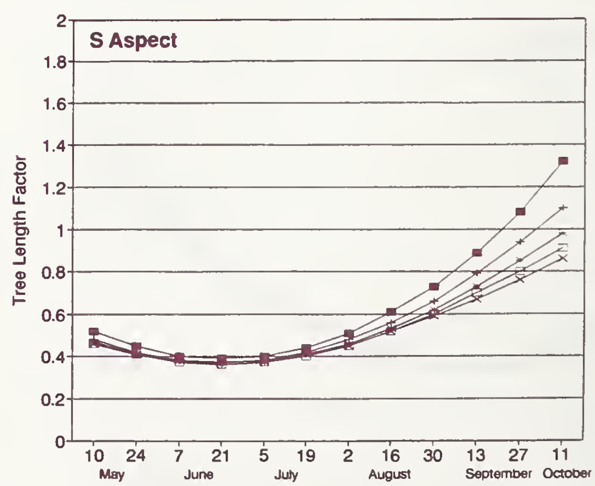
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.50		
N	15%	0.54	45%	0.66
	30%	0.60	60%	0.77
NE/NW	15%	0.53	45%	0.63
	30%	0.57	60%	0.70
E/W	15%	0.51	45%	0.55
	30%	0.52	60%	0.58
SE/SW	15%	0.49	45%	0.49
	30%	0.48	60%	0.50
S	15%	0.48	45%	0.47
	30%	0.47	60%	0.47







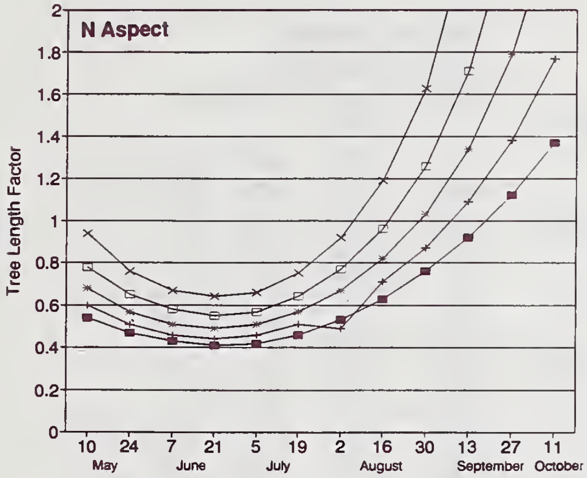


Flat Ground — 15% Slope — 30% Slope — 45% Slope — 60% Slope

Latitude 46°

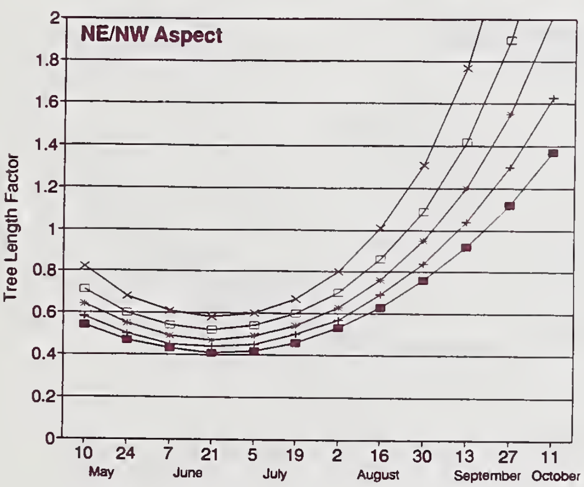
Reference area: 5 miles north of Grangeville, ID

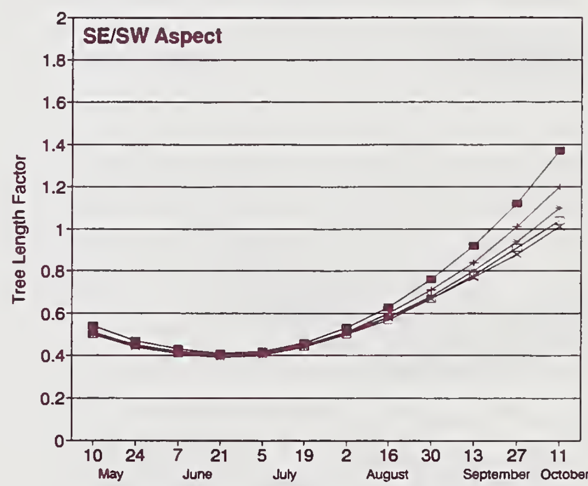
Tree length factors for cone-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

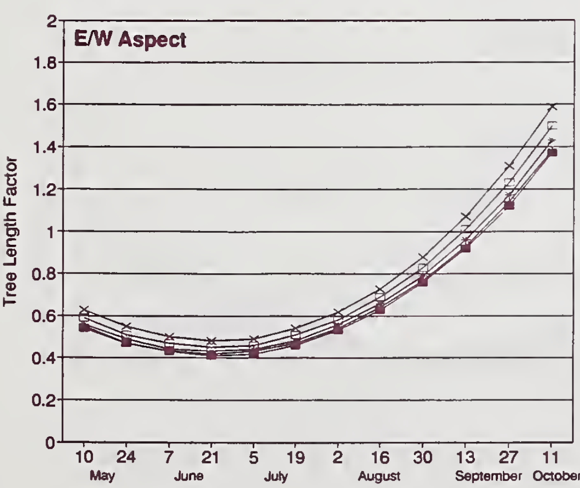


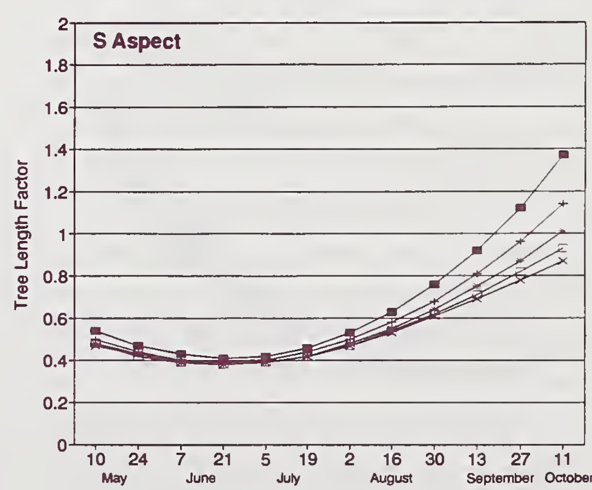
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.52		
N	15%	0.56	45%	0.70
	30%	0.62	60%	0.81
NE/NW	15%	0.55	45%	0.65
	30%	0.60	60%	0.73
E/W	15%	0.53	45%	0.57
	30%	0.54	60%	0.61
SE/SW	15%	0.50	45%	0.50
	30%	0.50	60%	0.51
S	15%	0.49	45%	0.48
	30%	0.48	60%	0.48







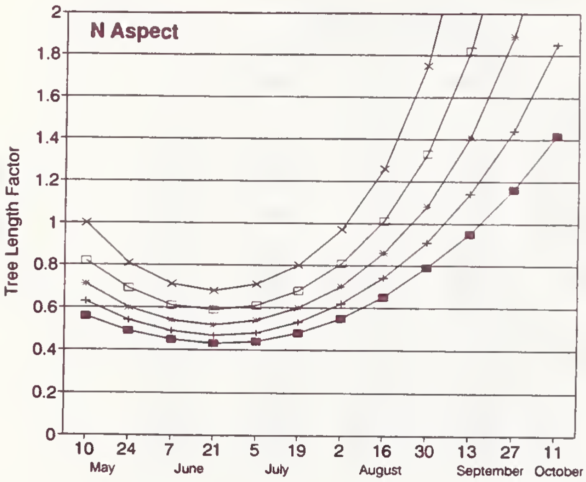


Flat Ground — 15% Slope — 30% Slope
45% Slope — 60% Slope

Latitude 47°

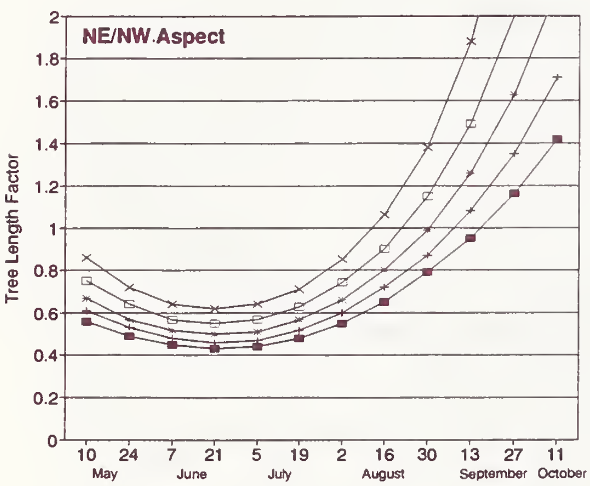
Reference area: 6 miles north of Boville, 2 miles south of Clarkia, ID

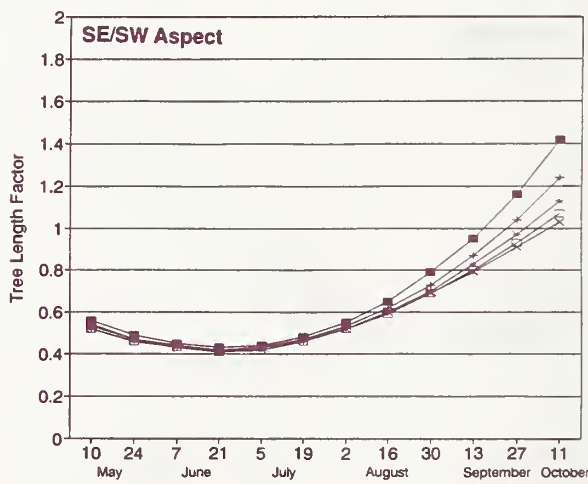
Tree length factors for cone-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

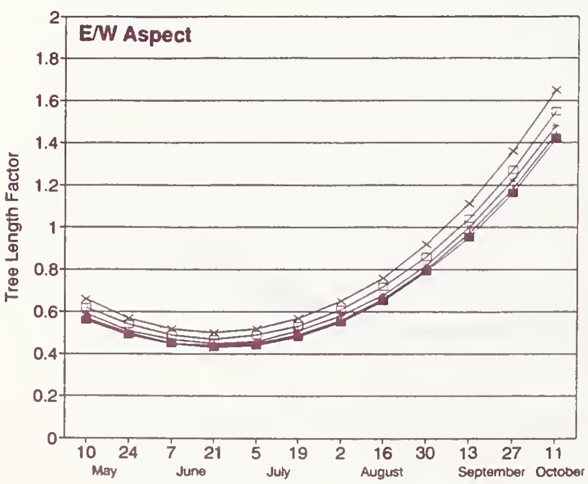


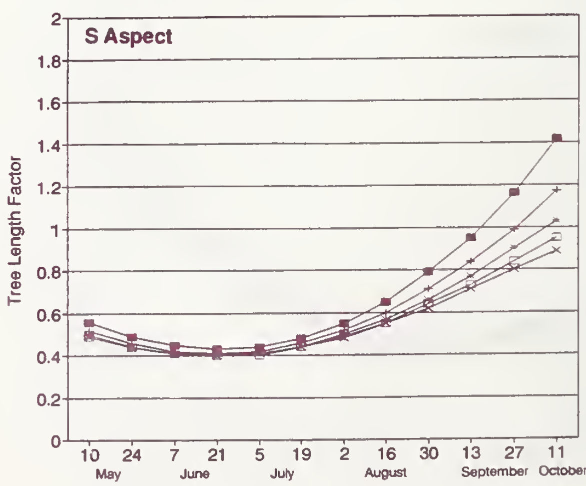
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.54		
N	15%	0.58	45%	0.73
	30%	0.65	60%	0.85
NE/NW	15%	0.57	45%	0.68
	30%	0.62	60%	0.77
E/W	15%	0.54	45%	0.59
	30%	0.56	60%	0.63
SE/SW	15%	0.52	45%	0.52
	30%	0.51	60%	0.53
S	15%	0.51	45%	0.49
	30%	0.50	60%	0.50







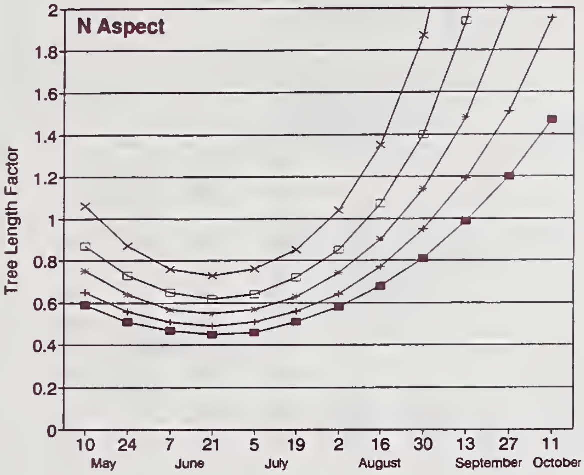


Flat Ground — 15% Slope — 30% Slope
45% Slope — 60% Slope

Latitude 48°

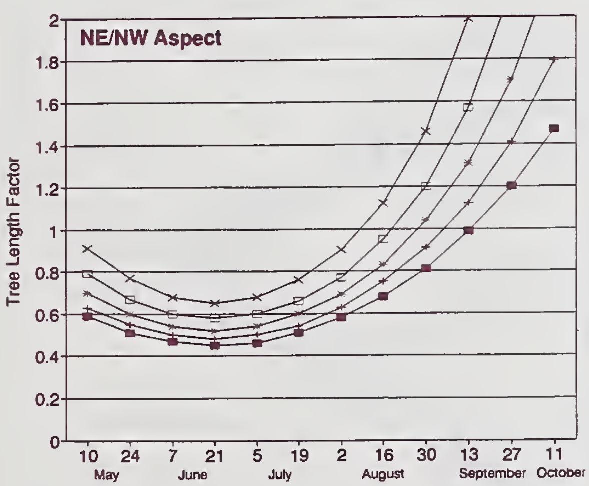
Reference area: 20 miles north of Coeur d'Alene, ID

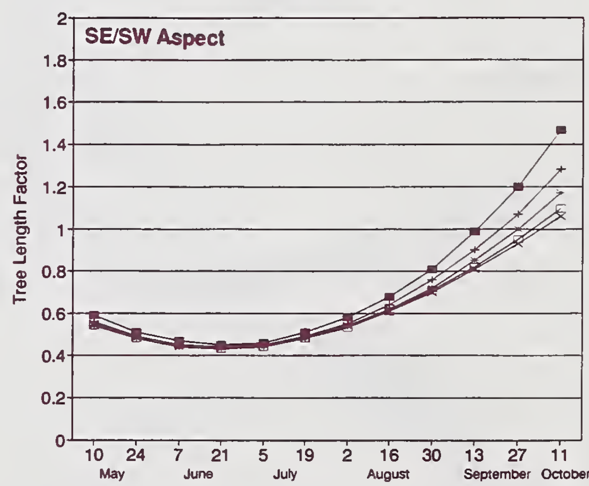
Tree length factors for cone-shaped trees at solar noon on eight aspects (N, NE/NW, E/W, SE/SW, and S) and five slopes (flat ground, 15, 30, 45, and 60 percent) from May 10 through October 11.

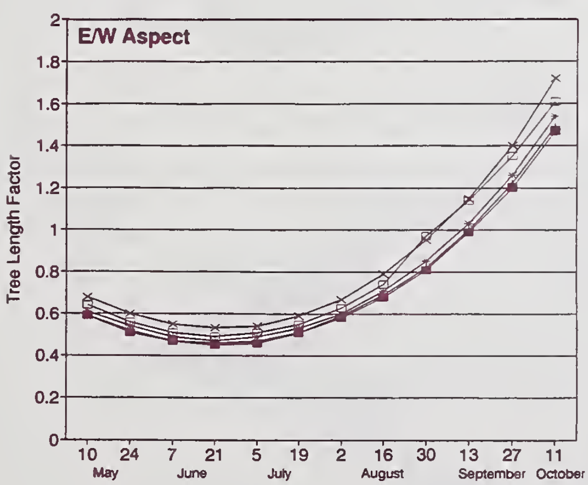


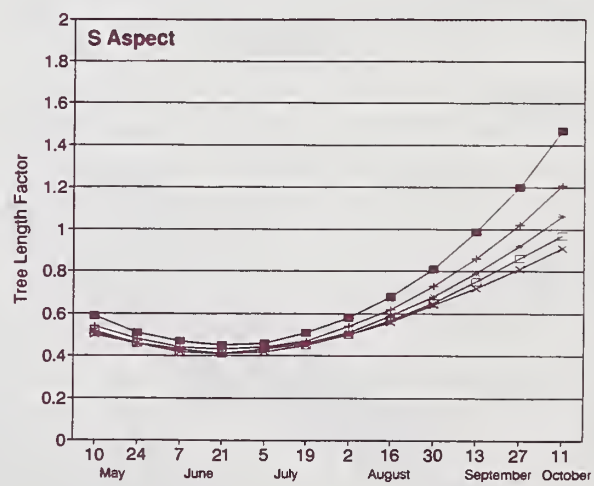
Shortest shadow
June 21 at solar noon

	Slope	Len.	Slope	Len.
Flat		0.56		
N	15%	0.61	45%	0.76
	30%	0.68	60%	0.89
NE/NW	15%	0.59	45%	0.71
	30%	0.65	60%	0.81
E/W	15%	0.56	45%	0.61
	30%	0.58	60%	0.65
SE/SW	15%	0.54	45%	0.53
	30%	0.53	60%	0.54
S	15%	0.53	45%	0.51
	30%	0.51	60%	0.51





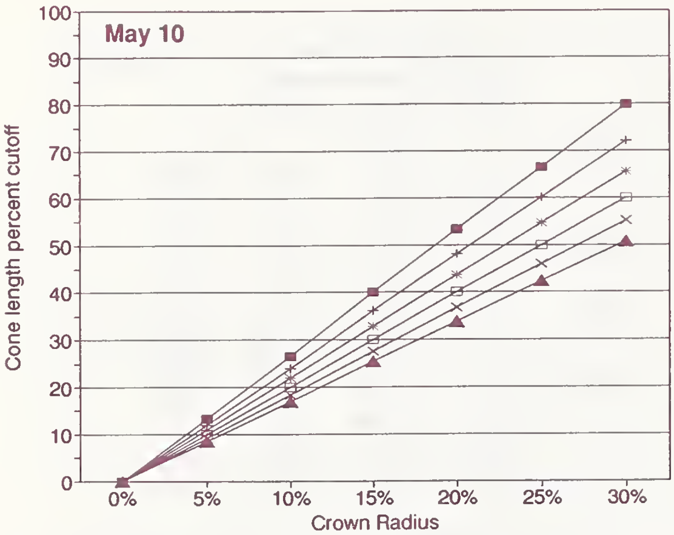




Flat Ground — 15% Slope — 30% Slope — 45% Slope — 60% Slope

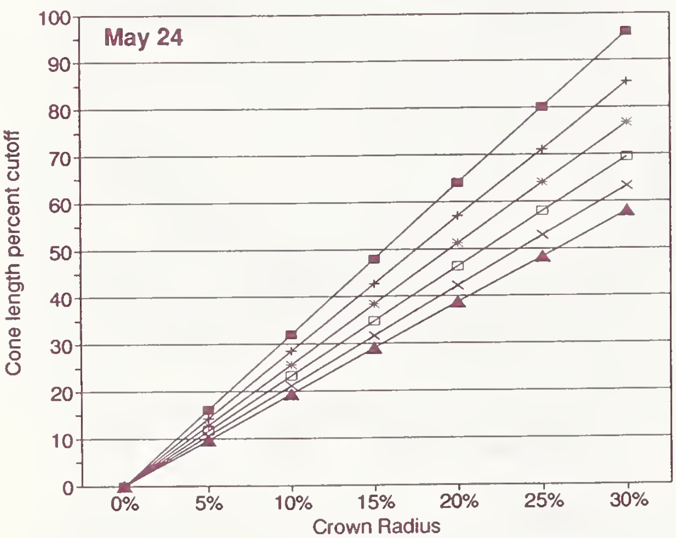
Appendix G

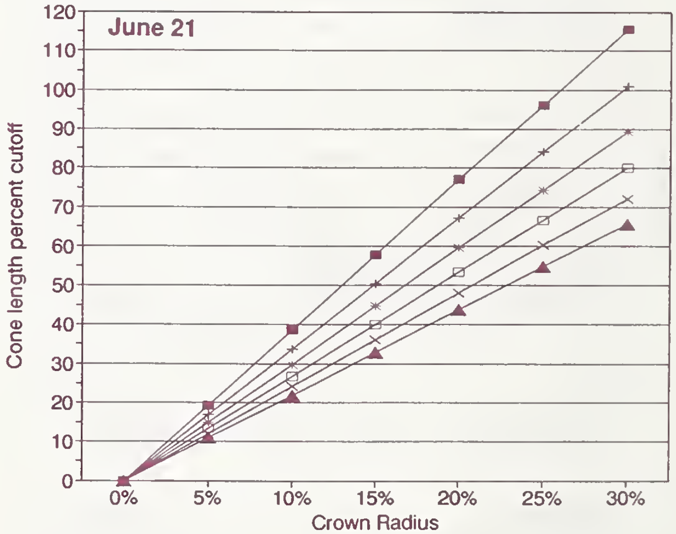
Cone Length Percent Cutoff for Determining Crown Radius Correction by Date and Latitude

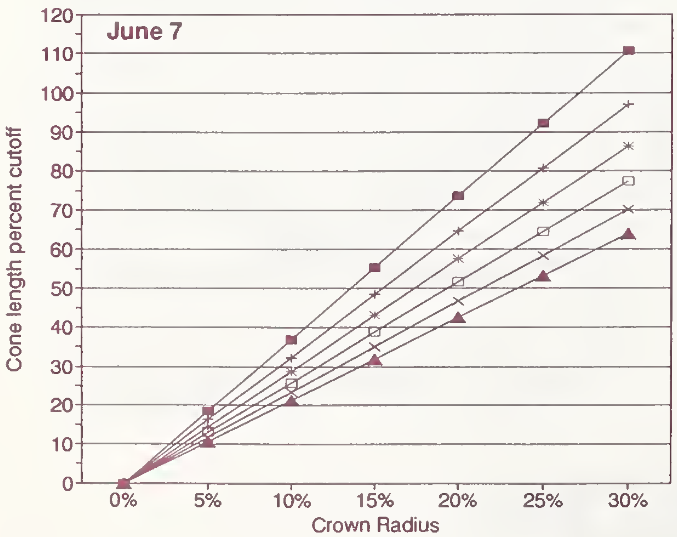


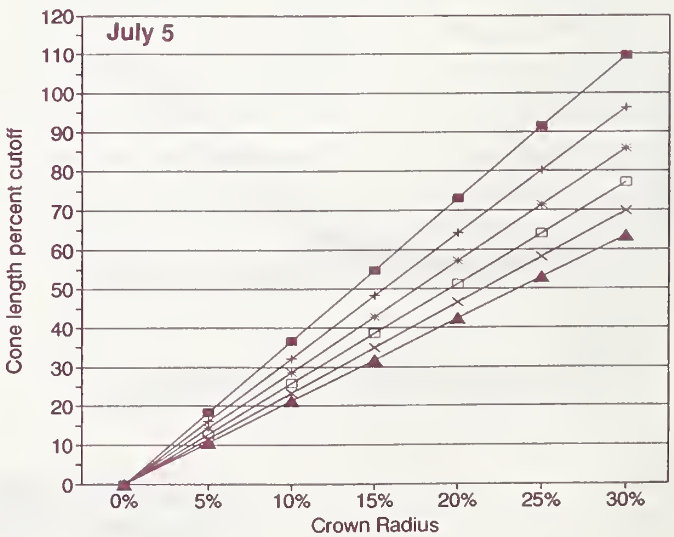
Cone length percent cutoff
June 21

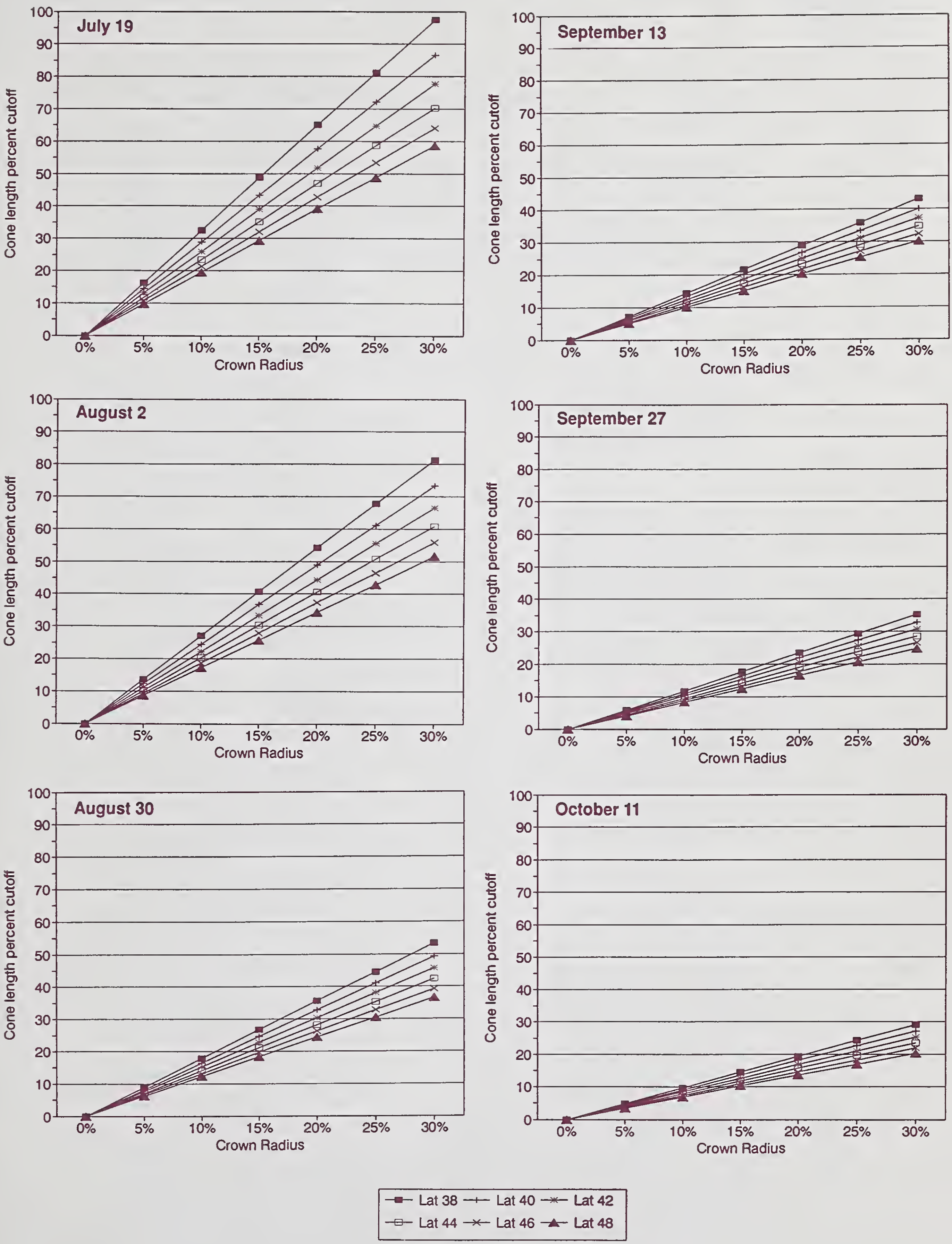
Latitude	Crown radius 0%	5%	10%	15%	20%	25%	30%
	Cone length percent cutoff						
38	0	19	39	58	77	96	116
39	0	18	37	54	72	90	109
40	0	17	34	50	67	84	101
41	0	16	32	48	64	78	95
42	0	15	30	45	60	71	89
43	0	14	29	43	57	69	90
44	0	13	27	40	53	67	80
45	0	12	26	38	51	64	76
46	0	12	24	36	48	60	72
47	0	11	23	35	46	57	69
48	0	11	22	33	44	54	66










July 19
August 2
August 30
September 13
September 27
October 11
Cone length percent cutoff
Crown Radius
0 10 20 30 40 50 60 70 80 90 100
0% 5% 10% 15% 20% 25% 30%
Lat 38
Lat 40
Lat 42
Lat 44
Lat 46
Lat 48

Geier-Hayes, Kathleen; Hayes, Mark A.; Basford, Douglas D. 1995. Determining individual tree shade length: a guide for silviculturists. Gen. Tech. Rep. INT-GTR-324. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 59 p.

This guide provides a method for determining shade lengths and shade patterns of individual overstory trees from southern Utah to northern Idaho from May 10 through October 11. The guide can be used to tailor tree marking to prescription requirements. It provides graphs and tables for determining the shortest shadow for any day and for shadow lengths 2 hours before and after solar noon for any location based on latitude and average overstory height. The guide contains other descriptions of shade patterns.

Keywords: overstory, regeneration, solar radiation, shadows, tree marking

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

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